TITLE:
Retrofit Methods for Exposed Sidewalls Adjacent to a Collapsed Row Home : Final Report

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Dwellings--Maintenance and repair
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This Civil and Architectural Engineering Senior Design Project Report analyzes retrofit techniques proposed to brace recently exposed sidewalls adjacent to collapsed row homes in North Philadelphia, Pennsylvania. The project also includes details for retrofitting the foundation wall.

Steel was considered for the sidewall, but timber was chosen for ease of installation and low material cost. The analysis of the bracing design followed the un-reinforced masonry section of the ACI 530 code (ACI 530 limits outward deflection of masonry walls to 0.7% of the wall height).

The report recommends grout injection for the foundation wall retrofit and incorporates a drainage system into the final below grade retrofit of the party wall.

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# Retrofit Methods for Exposed Sidewalls Adjacent to a Collapsed Row Home

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*Group # CAE 07*

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*Final Report Submitted: May 24, 2001*

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May 23, 2001

City of Philadelphia
Department of Licenses and Inspection
Room 720 - Municipal Service Building
Philadelphia, PA 19102

Dear Sir/ Madam:

OK Consultants has reviewed the structural integrity of the newly exposed party wall of the case study row home. This wall is declared dangerous, as it is susceptible to failure by buckling.

In general, there are several methods of repairing the newly exposed sidewalls, as we have presented in this Progress Report. Of the design alternatives, the most efficient bracing retrofit technique for the case study row home would be to embed steel tees into the masonry sidewall at mid-height between the floors. A wide-flange flexural member would be cantilevered up from the ground and connected to the tees at mid-length along the party wall. A geotechnical investigation would be required to determine the bearing capacity of the fill and therefore the proper foundations for the wide-flange beam. In addition, the effects of soil pressure on the existing footings would have to be analyzed.

The most economical below grade retrofit would involve installing a geocomposite drainage system and grout injecting the existing limestone foundation wall. The geocomposite consists of a geonet and felt geotextile along with a drainage pipe at the base. The geocomposite system would relieve hydrostatic pressure currently being experienced against the limestone foundation wall.

OK Consultants performed an economic analysis for the proposed sidewall retrofit, which totaled $7,200.00. The cost to retrofit the case study row home's party wall was then compared with the real estate value of a row home, and the City of Philadelphia's retrofit budget per row home. From the final cost estimation, it was determined that retrofitting the newly exposed sidewall was approximately three times the budget allocated by the city to repair deteriorated row homes. In lieu of structurally and economically analyzing the case study row home, OK Consultants recommendation to the city is that the city research further into the cost benefit ratio of retrofitting the home vs. demolishing and reconstructing the deteriorated row homes in North Philadelphia. In addition, social and political aspects of reconstructing the neighborhoods should be analyzed.

Enclosed for your review is a detailed final report of the main investigation performed by OK Consultants.

Sincerely,

Melissa M. Kroskey
Principal -Structural Department

Hazel J. Ojany
Principal – Structural Department

# INTRODUCTION

OK Consultants has analyzed the retrofit techniques proposed to brace the newly exposed sidewalls adjacent to collapsed row homes in North Philadelphia. From the case study row home, a structural analysis performed by OK Consultants indicated that the party wall was susceptible to failure by buckling under service loads. Refer to Appendix A for load calculations. The low modulus of elasticity of the salmon brick coupled with eccentricity of loading reduced the stability of the sidewall. Two different materials steel and timber were investigated to brace the party wall against buckling. Steel retrofit techniques incorporated the use of either structural steel plates or steel tees that have been cut from wide-flange shapes. Timber was chosen for its ease of installation and low material costs.

The analysis of the bracing design followed the unreinforced masonry section of the ACI 530 code. The ACI 530 limits the outward deflection masonry walls to 0.7% of the wall height. This outward deflection analysis was utilized as a guideline in determining the strength of the brace required to prevent the wall from deflecting beyond serviceability limits. Some of the other factors affecting the design included; available working space on site, equipment required for installation, ease of connections and installation, and the economics of retrofit.

The retrofit technique recommend by OK Consultants for the foundation wall was based on increasing the tensile bond between the limestone and therefore its load carrying capacity. The foundation wall consists of limestone and deteriorated type O mortar, and is 18 inches wide, six feet tall. As per OK Consultants' Progress Report dated March 8, 2001, grout injecting of the foundation wall was the most economic retrofit solution. The introduction of a drainage system has also been incorporated in the final below grade retrofit of the party wall.

The final recommendation made by OK Consultants was based on economics. The cost of repairing the row home's party wall was compared with the current estimated value of the home.

## ABOVE GRADE RETROFIT TECHNIQUES

The above grade retrofit techniques that OK Consultants reviewed in the structural bracing of the newly exposed party wall are based on the use of either timber or structural steel. The analysis followed the allowable stress design guidelines as published by the American Institute of Steel Construction for steel and the National Design Standards published by the American Forest & Paper Association for timber.

The bracing was designed to limit the outward deflection of the wall to 0.7 percent of the height, the maximum serviceability deflection for masonry walls.[1] The above-grade wall was analyzed in sections between the floor/ roof joists. The height of the wall between joist supports is nine feet, corresponding to a maximum serviceability deflection of ¾ inches. From stability analysis of discrete bracing systems, the brace should be designed to withstand three percent of the vertical load at the point of the brace.[2] Refer to Appendix A for loading calculations.

### TIMBER BRACING

Timber sections were analyzed to brace the party wall at mid-height between floors. The first analysis was performed to determine the size of the cross-section for a single span of 35 feet across the length of the sidewall. Timber sections of structurally select wood approximately ten inches square would be required to brace the wall between the first floor and the second floor. Not only are these sections large for timber, they also require timber with a high modulus of elasticity of 1,900,000 psi. Since the timber sections were large, diagonal braces were analyzed at mid-length of the wall to decrease the span and size of flexural timber members required. Diagonal braces were also placed at each end of the wall.

When analyzed in two sections, the timber sizes decreased to 5"×6" and 4"×4". The diagonal bracing was connected to the horizontal sections using galvanized steel hangers sloped down at a 45-degree angle. Refer to Appendix B for manufacturer's hanger specifications. The maximum allowable load for the Simpson LEG3 top flange hanger is 9,665 pounds, which provides a factor of safety of 3.4. Mechanical brackets will also be provided at five feet on center and epoxy bolted into the masonry wall and connected to the horizontal timber with Simpson strong-tie nails. The maximum angle that diagonal timber bracing can be connected efficiently to the wall is 45 degrees. Therefore, the base of the brace between the first and second floors would be embedded into grade approximately 8 feet out from the edge of the party wall. However, since the empty lot is only 14 feet wide, there would not be adequate room to install the diagonal brace for the upper level, which would extend 17 feet out from the edge of the party wall when placed at a 45-degree angle. Therefore, bracing at the upper level would be efficiently

[1] Drysdale, Hamid, and Baker: *Masonry Structures: Behavior and Design*. The Masonry Society: Boulder, Colorado, 1999.

[2] Galambos, Theodore: *Guide to Stability Design Criteria*. John Wiley & Sons: New York, 1998.

accomplished by bracing over the demolished unit's lot, connecting the two homes together.

The method of diagonal bracing and horizontal bracing between the two row homes adjacent to a collapsed unit was propose to the City of Philadelphia. Refer to Appendix C for timber bracing calculations. However, our client requested that the retrofit would impose minimally on the demolished lot. If the diagonal timber bracing had been incorporated, it would have hindered the use of the empty lot. With over 2,000 row homes demolished in North Philadelphia, this would be a lot of wasted space for a city growing at astronomical rates. Also, the fear of significant damage to the structural system would result if anyone were to impose stresses on the bracing, for example, by hanging heavy objects from the timber brace. Therefore, OK Consultants proceeded to analyze bracing the sidewall with steel.

## STRUCTURAL STEEL BRACING

### a) Steel Plates

One of the advantages of using steel plates to brace the sidewall was that the plates would be easily covered for aesthetic appeal. Initially, it was assumed that the plates would be less than three inches wide and easily covered with stucco to hide the retrofit. However, due to the rectangular shape of the plates, the inertia required to limit the deflection of the wall could only be obtained with a section of substantial thickness. Refer to Appendix D for retrofit calculations. The plate bracing the wall between the second floor joists and the first floor joists along the 35-foot wall length required a plate with inertia of 63 $in^4$. A plate with that inertia would have to be 4 inches thick by 12 inches wide, or comparable in size. The weight of that member would be 163 lb/ft, a heavy section that would require a 3-ton capacity crane or lift for installation. Since steel prices are governed by weight, OK Consultants decided to reduce the size of the plate required by decreasing the span. Also, the availability of a steel plate that size is limited, further increasing costs. The structural steel chosen for the plate analysis was ASTM A36. Stronger steel was not needed since the flexural and shear strength was not a critical factor in the analysis and deflection governed.

The second design alternative OK Consultants looked into analyzing was dividing the plate span into two equal sections, which would require a support against translation at the center of the wall's length. The only way to brace the plates against translation at the center of the 35-foot length would be to run a vertical or diagonal member extending from the ground. Two options were considered. First, utilizing a steel flexural member extending vertically from the ground to the mid-height of the sidewall between the roof joists and floor joists. The vertical steel beam would transfer the load from the horizontal steel plates into the ground. The wide-flange section would be connected to the horizontal plates by bolting through the flanges. In order to transfer the load from the base of the vertical flexural member into the soil, a concrete footing would be poured under the base and connected into the existing strip footing for the masonry wall. It should be noted that a geotechnical investigation would be required to check the bearing capacity of the soil and adequately size the footing. It may also be possible to connect the beam into the existing wall footing, therefore eliminating the construction of a new footing.

Since the addition of a vertical bracing element would increase the thickness of the retrofit protruding from the sidewall, the steel plate no longer proves economical. In summary, the option of utilizing steel plates was ruled out based on the following:

1. For a steel plate spanning horizontally along the 35-foot wall length, the section required was massive. Furthermore, material, fabrication, and installation costs make this design alternative uneconomical.
2. With two steel plate sections, each 17'-6" in length, a vertical member was required to prevent translation at mid-length of the wall. The vertical element further increases the thickness of the retrofit, eliminating the advantages of using a thin steel plate.

**STRUCTURAL STEEL BRACING**
**b) Steel Tees**

Bracing the party wall with steel tees at mid-height between the floors provides several advantages over steel plates. First, the web of the tee would be embedded into the masonry wall. The bearing of the steel tee on the brick would provide a better connection between the two materials, as opposed to a self-supporting steel plate. Also, the inertia provided by the tee is greater than the inertia of a plate, therefore, reducing the amount of steel required to brace the wall.

Sizing of the steel tees was based on the desirable embedment depth of $^2/_3$ of the wall thickness, or approximately five inches. Therefore, it was preferable to use a WT5. The type of steel chosen for the tees was ASTM A992, with yield strength of 50 ksi and an ultimate strength of 65 ksi. The analysis was done utilizing one tee between each floor spanning the entire 35-foot length. The section required between the second floor joists and first floor joists was a WT 6×85. For a 35-foot long member weighing 85 lb/ft, a small crane or lift with a capacity of one and a half tons would be required. Again, material, fabrication, and installation costs would make this design technique uneconomical.

The 35 foot span of the tee was reduced to 17'-6" by connecting two WT sections at mid-length along the wall. Once again, a support would be required at the connection to prevent translation of the tees. This support could either be a diagonal timber strut or a vertical wide-flange beam. From the structural analysis, it was determined that a WT 5×6 would be required between the first floor and second floor, and a WT 4×5 between the second floor and the roof. However, it would be more economical to use the same section, the WT 5×6, at both locations. The weight of steel required for this method is minimal at six pounds per foot, and a small lift with a 250-pound capacity would be needed for installation. The most economical vertical flexural member at the tee connection would be a W14 × 22. The flanges of the wide flange will be bolted to the flanges of the tees at the connection.

The connections at the other ends of the horizontal tees, into the row home's exterior front and back walls, will be made with plates transferring the load into the exterior masonry wall. The plate will bear into the front and rear masonry walls a minimum of 8 inches and have and protrude from the wall 5 inches so that it can be bolted and welded to an angle. The steel angle will have 5-inch equal legs and be bolted through the flange of the embedded tee and bolted to the bearing plate. The protrusion of the bearing plate will require the flanges of the tee to be coped at the intersection. The bearing plate should have a minimum thickness of ½ inch and the angle shall be ¼ inch thick. The area of the bearing plate required was a function of the masonry compressive strength and the reaction from the embedded tees. Refer to Appendix E for steel tee retrofit calculations.

OK Consultants has analyzed the most economical retrofit techniques for the party wall and believe the embedded tees with a connection at mid-length along the wall would provide adequate structural stability with ease of installation.

## RETROFIT BELOW GRADE

The below grade geotechnical analysis of the foundation wall was analyzed utilizing information attained from geotechnical investigations performed by Lippincott Engineering Associates in the Logan section of Philadelphia.[3] Since row home construction was relatively similar throughout the city in the 1900's, OK Consultants believe this information would be applicable to the North Philadelphia area.

During OK Consultant's Phase 2, the main investigation, it was determined that the introduction of earth and hydrostatic pressures on the foundation wall induced the probability of failure in the row home's foundation wall. As displayed in Appendix F, the six-foot tall, 18-inch wide foundation wall comprises of limestone bonded by type O mortar. The foundation wall is supported on a concrete footing approximately one foot thick, three and a half feet wide. In addition to the introduction of lateral forces on the foundation wall, geotechnical investigations indicate that over the years, the limestone wall's mortar has decayed and currently displays material properties of sand, the main composite of mortar. This mortar decay has resulted in reduced resistance to tensile stresses within the foundation wall. Refer to Appendix G for the foundation wall integrity analysis. This below grade study made it evident to OK Consultants that there was a need to increase the structural stability of the party wall below grade.

In Phase 2, the 80 percent cost estimation performed by OK Consultants, refer to Appendix H – Section 1, indicated that the most economical retrofit technique for the foundation wall would be to restore the current foundation wall's structural stability by grout injection. A high slump grout would be required to fill the voids within the limestone while, therefore restoring the tensile capacity of the wall.

In addition to grout injecting the limestone wall for increased stability, OK Consultants recommends the introduction of a drainage system at the base of the footing to relieve hydrostatic pressures acting on the foundation wall. Excavation will be required for drainage installation. During soil excavation, safety must be observed, as there is a possibility of the hole caving in on a laborer at depths exceeding five feet. OK Consultants therefore recommends that excavation extend further back away from the party wall of the row home. Refer to Appendix I for approximate earthwork excavation requirements.

Since the exterior face of the foundation wall will be exposed during excavation, grout injection should be performed both from the interior and exterior of the home. Grout injection from the interior is recommended, as the wall surface is the cleaner of the two facades. This will consequently prevent any need to water down the wall and consequently increase the wall's current moisture content. This grout injection process will begin at the base and continue up the foundation wall to ensure that the grout has

[3] Volume 1: Geotechnical Investigation - City of Philadelphia: Logan Section, Lippincott Engineering Associates, Delanco, NJ

successfully bonded to the current limestone wall. In addition, grout injecting from the base up prevent further wall damage due to the inducement of additional cracks.

The drainage system that will be employed is a subsurface geocomposite. This geocomposite will comprise of a single-dimple geonet and two-ply felt. OK Consultants has researched the geocomposites market and recommends using Hydraway 300®, manufactured by Solutia. Refer to Appendix J. Hydraway 300 has many features and benefits. Not only is Hydraway 300 lightweight and chemically resistant, but it also displays high compressive strengths and water flow rates. Furthermore, the geocomposite has strong fusion bonding characteristics, a built-in protective board and is sold as individually wrapped rolls and is consequently easy and economical to install.

Hydraway 300 can either be installed with the perforated pipe at the base of the footing as shown in Appendix J, figure 3, or by laying the perforated pipe at the top of the footing as shown in figure 4. OK Consultants recommends that the latter technique be employed in order to prevent additional excavation of soil.

The roof gutters of row homes are connected to downspouts, which drain directly into the sanitary sewer lateral. The lateral, which is installed either under the house or inside the basement, depending upon the basement's relative elevation with respect to the street's main sewer, consists of cast iron pipe within the building. Outside the building area, the lateral sewer consists of vitrified clay pipe. Each lateral has a vent at the curb and is connected via a vitrified clay pipe to the main street sewer. According to the Sewer Code of the City of Philadelphia, the building owner owns the lateral.

The perforated pipe in the Hydraway 300 drainage system will be connected to the current four-inch vitrified clay lateral sewer pipe. In sanitary flow systems composed of any material, changes in direction must be made with easy bends. To prevent clogging or fouling by the solid materials in the piping, OK Consultants recommends the use of a $^1/_8$ bend plus a 45-degree Y, or a ¼ bend long sweep[4]. All connections will be performed using couplings. Should the need arise to use dissimilar metal connections; dielectric unions must be used to prevent corrosion due to electrolysis.

During excavation and installation of the drainage system, OK Consultants recommends that safety be observed, as workers will be working around existing electrical, gas, television, and cable ductwork.

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[4] Stein and Reynolds: *Mechanical and Electrical Equipment for Buildings* John Wiley & Sons Inc, Canada, 2000

## ECONOMIC ANALYSIS

The final economic analysis has been performed at 95 percent. From the economic analysis, it has been determined that the retrofit of the above grade wall is approximately $7,200.00. As displayed in the Cost Estimation, refer to Appendix H –Section 2; the cost to retrofit the newly exposed side wall is approximately three times the budget allocated by the City of Philadelphia for the retrofit of deteriorating homes. It should be noted that the case study home was used as a worse case scenario in the analysis of the retrofit of row homes in North Philadelphia. In addition, geotechnical investigations have not been included in the final cost estimation for the retrofit of the newly exposed sidewalls.

## BUDGET

The budget presented below is in respect to OK Consultants' consulting fees generated for Phase 3 – Proposed Retrofit Method.

| | Rate | 3- Month Fee (US$) |
|---|---|---|
| **Consulting Fees** | $ 80/hour | 48,000.00 |
| **Travel Expenses** | 50/month | 150.00 |
| **Scheduling** | 40/hour | 2,400.00 |
| **Total** | | **$ 50,550.00** |

Table 1 – Consulting Budget for Phase 3

The total consulting fee for the three phases of this project is $181,800.00.

## WIND LOADS (1611 BOCA)

Exposure Category B
Basic Wind Speed $(V) = 80$ Mph (PHILA.)
Importance Factor $(I) = 1.0$
Orientation - front faces North

WINDWARD WALL (NEWLY EXPOSED PARTY WALL, EAST FACE)

$$P = P_v I \left[ K_z G_h C_p - K_h (GC_{pi}) \right]$$

$P_v$ = velocity pressure = 16.4 PSF

$G_H$ (Gust Response Factor)

1.65 (0-15')
1.59 (20')
1.54 (25')

$K_z$ (Velocity Pressure Coef.)

0.37 (0-15')
0.42 (20')
0.46 (25')

$K_h = 0.46$ (25')

$C_p$ = Wall pres. coef. = 0.8
$GC_{pi} = +0.75$
$\quad\quad\;\; -0.25$

| $Z$ | $K_z$ | $G_h$ | P(psf) w/ (+)$GC_{pi}$ | P (PSF) w/ (-)$GC_{pi}$ |
|---|---|---|---|---|
| 0-15' | 0.37 | 1.65 | 1.37 | 10.20 |
| 20' | 0.42 | 1.59 | 2.12 | 11.0 |
| 25' | 0.46 | 1.54 | 2.65 | 11.5 |

Assume suction since loads are greater w/ (-) $GC_{pi}$

## ROOF LOADING

DL = 13.5 PSF
LL = 20 PSF

## $2^{ND}$ FLOOR JOISTS

DL = 15 PSF
LL = 30 PSF (Majority Sleeping Rooms)

## $1^{ST}$ FLOOR JOISTS

DL = 15 PSF
LL = 40 PSF

## WT. OF MASONRY WALLS

L = 35' H = 25' Area = 875 $ft^2$
8" THICK

Weight per inch of wall thickness for Clay Masonry = 10 $lb/ft^2$ (Drysdale, Hamid, + Baker : "Masonry Structures - Behavior + Design" PG. 869)

Total wt. of wall = $10 \frac{lb}{ft^2 \cdot in}(7.625")(875 ft^2)$ = 67 kips OR 1906 lb/ft

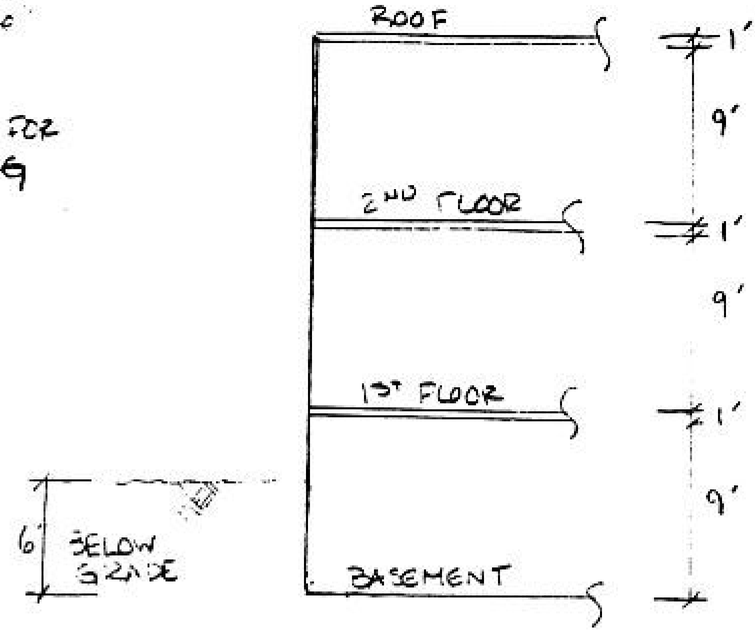
Wt. of wall from top down to 2nd floor joists
$= 10 \frac{lb}{ft^2 \cdot in}(7.625")(10')(35')$ = 27 kips OR 763 lb/ft

Wt. of wall from top down to 1st floor joists
$= 10 \frac{lb}{ft^2 \cdot in}(7.625")(20')(35')$ = 54 kips OR 1525 lb/ft

## CURRENT CONDITIONS OF NEWLY EXPOSED SIDEWALL

ANALYSIS PARAMETERS:
- JOIST SPACING 16"
- JOIST SPAN 15'
- 9' FLOOR HT.
- 1' HT. PER FLOOR FOR JOISTS + FLOORING
- 2" × 10" JOISTS
- $f'_m = 275$ PSI

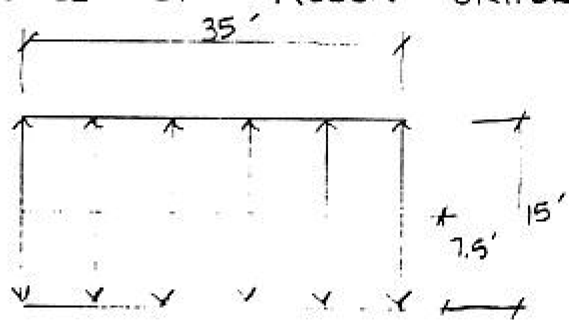
ASSUME:
- NO DEBONDING OF WYTHES




ELEVATION OF ROW HOME

## TRIBUTARY AREA FOR PARTY WALL

- JOISTS SPACED CLOSELY ∴ ASSUME UNIFORMLY DISTRIBUTED LOADS




FLOOR AREA

$A = 35'(7.5') = 262.5\ ft^2$

## LOADS ON PARTY WALL FROM ROOF/FLOOR DL

ROOF LOAD = (13.5) PSF(262.5 $ft^2$)/35' = 101 lb/ft

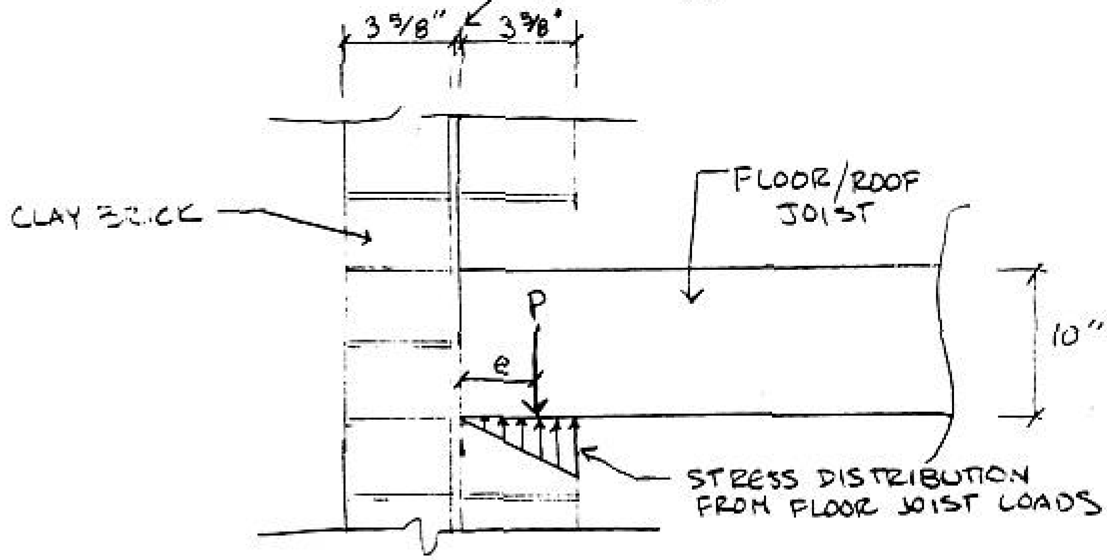
$2^{ND}$ FL. LOAD = (15 PSF)(262.5)/35 = 113 lb/ft

$1^{ST}$ FL. LOAD = (15 PSF)(262.5)/35 = 113 lb/ft

## JOIST/WALL CONNECTIONS

SINCE JOISTS CAN PULL OUT OF WALL DURING DEMOLITION, SEVERAL CASES WILL BE ANALYZED FOR DIFFERENT PULLOUT LENGTHS

### CASE 1 - JOIST EMBEDDED 4"




SECTION

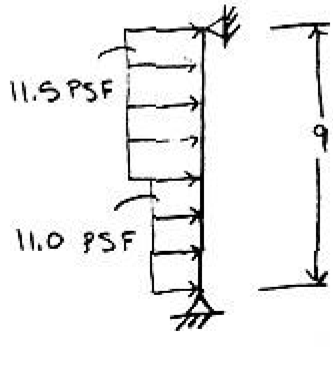
LOCATION OF ECCENTRICITY

$$e = 4'' \left(\tfrac{2}{3}\right) = 2\tfrac{2}{3}''$$

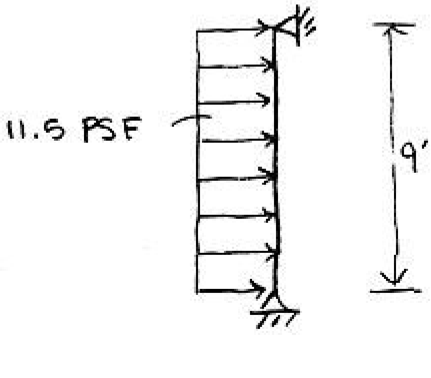
* FOR SIMPLICITY, WALL WILL BE ANALYZED AS SIMPLY SUPPORTED SECTIONS BETWEEN FLOORS

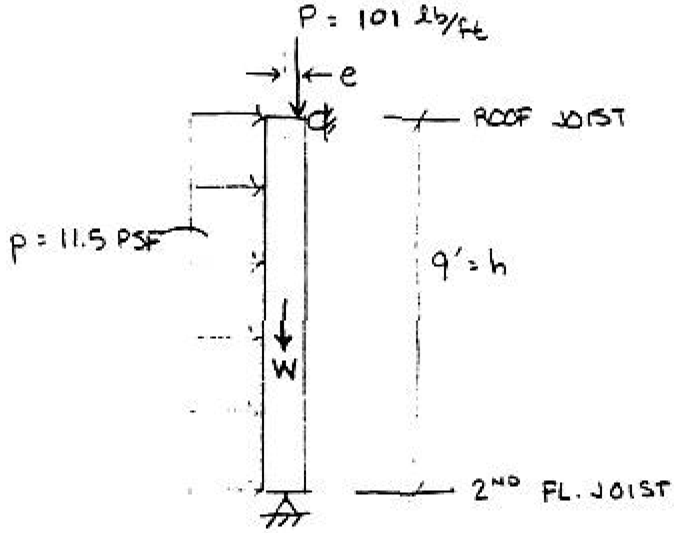
### WALL SECTION BTWN. ROOF + 2ND FLOOR JOISTS

ACTUAL WIND LOAD




SIMPLIFIED WIND LOAD






PERFORM ANAYSIS UNDER COMBINED AXIAL LOAD + OUT-OF PLANE BENDING

W = Wall wt = 763 lb/ft

$I = \frac{bt^3}{12} = \frac{12(7.625)^3}{12} = 443\ in^4/ft$

$A = 7.625\,(12) = 91.5\ in^2$

$S = I/(7.625/2) = 116\ in^3/ft$

Moment @ Mid-Height

$$M = \frac{ph^2}{8} + \frac{Pe}{2} = \frac{11.5\ PSF\,(9')^2}{8} + \frac{101\ lb/ft\,(2\tfrac{2}{3}'')}{2}\left(\frac{1\ ft}{12''}\right)$$

$M = 128\ ft \cdot lb/ft$ (IGNORING LL)

Load @ Midheight

$P = 763\ lb/ft / 2 + 101\ lb/ft = 483\ lb/ft$ (IGNORING LL)

CHECK FOR FLEXURAL TENSION STRESS: (IGNORE LL)

$$f_t = -\frac{P}{A} + \frac{My}{I} = \frac{-483\ lb/ft}{(12)(7.625)in^2} + \frac{128\ ft \cdot lb/ft\,(3.813'')(12''/ft)}{443\ in^4/ft} = 7.95\ PSI$$

ALLOWABLE $f_t$ = 40 PSI (ACI 530 - Table 2.2.3.2 FOLLOWS MSJC + BOCA REFERENCES MSJC)

7.95 PSI << 40 PSI ∴ OK

CHECK FOR COMPRESSION (USING LL + DL)

$r = \sqrt{I/A} = \sqrt{443/91.5} \Rightarrow r = 2.2''$ = radius of gyration

$$\frac{kh}{r} = \frac{1.0(9')(12''/ft)}{2.2''} = 49$$

If $\frac{kh}{r} > 99$, $F_a = \frac{f'_m}{4}\left(\frac{70r}{kh}\right)^2$, where $F_a$ = allow. comp. stress, $f'_m$ = comp. strength of masonry

If $\frac{kh}{r} \leq 99$, $F_a = \frac{f'_m}{4}\left[1 - \left(\frac{kh}{140r}\right)^2\right]$

(ACI 530 EQNS: 2-12 + 2-13)

$F_a = \frac{f'_m}{4}\left[1-\left(\frac{kh}{140r}\right)^2\right] = \frac{275\ PSI}{4}\left[1-\left(\frac{49}{140}\right)^2\right] = 60\ PSI$

$F_b = \frac{f'_m}{3} = \frac{275\ PSI}{3} = 92\ PSI$ (ACI 530 EQN. 2-14)

$f_a = \frac{P}{A} = \frac{(382+101+151)\ lb/ft}{(7.625'' \times 12'')} = 6.92\ PSI$ /ft of wall

$f_b = \frac{M}{S} = \left[\frac{(11.5\ PSF)(9')^2}{8} + \frac{(101+151)(2\,7/3'')}{2}\left(\frac{1\ ft}{12''}\right)\right]\left(\frac{1}{116\ in^3}\right) = 1.2\ PSI$

UNITY EQN. $\frac{f_a}{F_a} + \frac{f_b}{F_b} = \frac{6.9}{60} + \frac{1.2}{92} = \underline{\underline{0.128}} \leq 1 \therefore OK$

PREVENT SAFETY AGAINST BUCKLING

$P = 1/4\, P_e$ (ACI 530 EQN. 2-11)

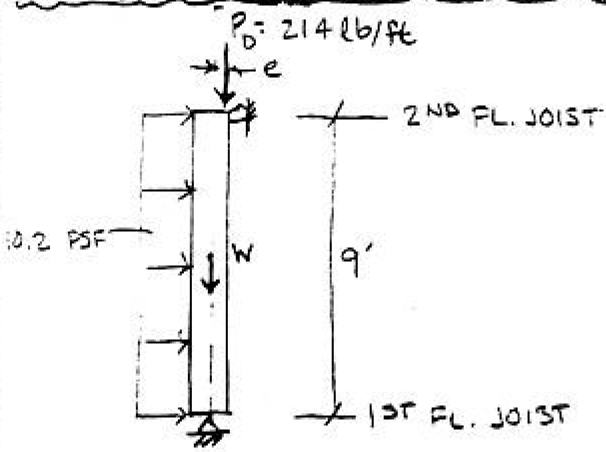
$P_e = \frac{\pi^2 E_m I}{h^2}\left(1 - .577 \frac{e}{r}\right)^3$ (ACI EQN. 2-15)

FOR CLAY MASONRY, $E_m = 700 f'_m = 192{,}500\ PSI$

$P_e = \frac{\pi^2 (192{,}500\ PSI)(443\ in^4/ft)}{(9 \times 12)^2}\left[1 - .577\left(\frac{2\,1/3''}{2.3''}\right)\right]^3 = 1960\ lb/ft$

$\underline{1/4\, P_e = 489\ lb/ft} > \underline{P = 483\ lb/ft}$ $\therefore$ OK

WALL SECTION BTWN. 2ND FL. & 1ST FL.




$S = 116\ in^3/ft$
$A = 91.5\ in^2$
$I = 443\ in^4/ft$

$P_D = 214\ lb/ft$
$P_L = 376\ lb/ft$

Wt. of wall above

Wall wt. @ Mid-Ht. = $763\ lb/ft + \frac{763}{2}\ lb/ft = 1143.75\ lb/ft$

LOAD @ Mid-Ht:

$P = 1143.75\ lb/ft + 214\ lb/ft = 1357.75\ lb/ft$ (IGNORING LL)

$P = 1144\ lb/ft + 214\ lb/ft + 376\ lb/ft = 1735\ lb/ft$ (DL+LL)

MOMENT @ MID-HT.

$$M = \frac{ph^2}{8} + \frac{P_e}{2} = \frac{10.2\,PSF\,(9')^2}{8} + \frac{214\,lb/ft\,(2.67'')}{2}\left(\frac{1'}{12''}\right) \Rightarrow M = 127\ ft\,lb$$
(IGNORING LL)

$$M = \frac{ph^2}{8} + \frac{P_e}{2} = \frac{10.2\,PSF\,(9')^2}{8} + \frac{(327+676)(2.67'')}{2}\left(\frac{1}{12}\right) \Rightarrow M = 169\ ft\cdot lb$$
(DL+LL)

Check Flexural Tension Stresses: (IGNORE LL)

$$f_t = -\frac{P}{A} + \frac{M}{S} = -\frac{1358\ lb/ft}{91.5\ in^2} + \frac{127\ ft\,lb}{116\ in^3} = \underline{-1.74\ PSI} < 40 \therefore \underline{O.K.}$$

Check Compression Stresses: (LL+DL)

$$f_a = \frac{P}{A} = \frac{1735\ lb/ft}{91.5\ in^2} = 19.0\ PSI$$

$$f_b = \frac{M}{S} = \frac{169\ ft\cdot lb}{116\ in^3}\left(\frac{12''}{ft}\right) = 17.5\ PSI$$

$$\frac{kh}{r} = \frac{1(9')(12''/ft)}{2.2} = 49$$

$$F_a = \frac{f'_m}{4}\left[1-\left(\frac{kh}{140r}\right)^2\right] = 60\ PSI$$

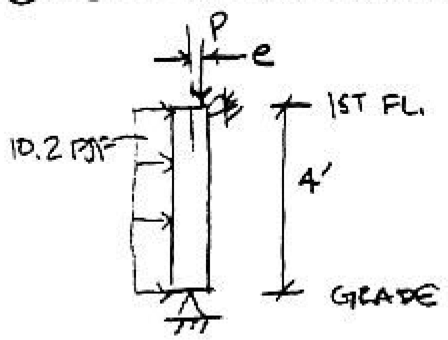
$$\frac{f_a}{F_a} + \frac{f_b}{F_b} = \frac{19\ PSI}{60\ PSI} + \frac{17.5\ PSI}{92\ PSI} = \underline{0.507} < 1 \therefore \underline{O.K.}$$

CHECK SAFETY AGAINST BUCKLING

$$P \le \tfrac{1}{4} P_e$$

$$\underline{\tfrac{1}{4}P_e = 489\ lb/ft} < \underline{P = 1359\ lb/ft} \therefore \underline{NOT\ ADEQUATE}$$

WALL SECTION BTWN. 1ST FL. JOISTS & GRADE




$S = 116\ in^3/ft$
$A = 91.5\ in^2$
$I = 443\ in^4/ft$

$P_D = 327\ lb/ft$
$P_L = 676\ lb/ft$

$$\text{Wall wt. @ Mid-Ht} = (763\ lb/ft)2 + 10\tfrac{lb}{ft^2\cdot in}(7.625'')(2') = 1298\ lb/ft$$

P@ Mid-Ht

$P = 1298 + 327 = 1625$ lb/ft (IGNORING LL)

$P = 1625 + 676 = 2301$ lb/ft (LL & DL)

M @ Mid-Ht

$$M = \frac{ph^2}{8} + \frac{Pe}{2} = \frac{10.2(4')^2}{8} + \frac{327(2.67)}{2}\left(\frac{1}{12''}\text{ft}\right) = 57 \text{ ft.lb (IGNORING LL)}$$

$$M = \frac{10.2(4)^2}{8} + \frac{(327+676)(2.67)}{2(12)} = 132 \text{ ft.lb} \quad \text{(DL+LL)}$$

CHECK FLEX. TENSION STRESSES

$$f_t = -\frac{P}{A} + \frac{M}{S} = -\frac{1625}{91.5} + \frac{57}{116}\left(\frac{12''}{ft}\right) = \underline{-11.9 \text{ PSI}} < 40 \therefore \underline{OK}$$

CHECK COMP. STRESSES

$$f_a = \frac{P}{A} = \frac{2301}{91.5} = 25.1 \text{ PSI}$$

$$\frac{kh}{r} = \frac{(1)(4')}{2.2''}\left(\frac{12''}{ft}\right) = 22$$

$$f_b = \frac{M}{S} = \frac{132}{116}(12) = 13.7 \text{ PSI}$$

$$F_a = \frac{f'_m}{4}\left[1 - \left(\frac{kh}{140r}\right)^2\right] = \frac{275 \text{ PSI}}{4}\left[1 - \left(\frac{22}{140}\right)^2\right] = 67 \text{ PSI}$$

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} = \frac{25.1}{67} + \frac{13.7}{92} = \underline{0.522} < \underline{1 \therefore O.K.}$$

CHECK BUCKLING

$$P_e = \frac{\pi^2 E_m I}{h^2}\left(1 - .577\frac{e}{r}\right)^3 = \pi^2 \frac{(192{,}500 \text{ PSI})(443 \text{ in}^4)}{(4 \times 12)^2}\left(1 - .577\frac{(2.67)}{2.2}\right)^3$$

$= 9880$ PLF    $\frac{1}{4}\underline{P_e = 2470 \text{ PLF}} > \underline{P_{wh} = 1625 \text{ PLF}} \therefore \underline{O.K.}$

## CASE 1: Joists Embedded 4"

### Roof Joists to 2nd Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 382 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 101 | PLF |
| Live Load | $P_L$ | 151 | PLF |
| Eccentricity of Load | e | 2.67 | in |
| Wind Pressure | p | 11.5 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 128 | ft•lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 483 | PLF | |
| Flexural tension stress | $f_t$ | 7.90 | PSI | |
| | OK | | **($f_t$ < 40 PSI)** | |

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 144 | ft•lb/ft | |
| Load at mid-height | $P_{mh}$ | 634 | PLF | |
| Stress from axial load | fa | 6.9 | PSI | |
| Stress from bending | fb | 14.9 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.278 | | |
| | OK | | **(Must be less than 1)** | |

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 1952 | PLF |
| Pe/4 | 488 | PLF |
| $P_{mh}$ | 483 | PLF |
| **OK** | | |

**(Pmh < 1/4 Pe)**

## CASE 1: Joists Embedded 4"

## 2nd Floor Joists to 1st Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1145 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 214 | PLF |
| Live Load | $P_L$ | 376 | PLF |
| Eccentricity of Load | e | 2.67 | in |
| Wind Pressure | p | 10.2 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 127 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1359 | PLF | |
| Flexural tension stress | $f_t$ | -1.74 | PSI | |
| | **OK** | | **($f_t$ < 40 PSI)** | |

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 169 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 1735 | PLF | |
| Stress from axial load | fa | 19.0 | PSI | |
| Stress from bending | fb | 17.4 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.505 | | |
| | **OK** | | **(Must be less than 1)** | |

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 1952 | PLF |
| Pe/4 | 488 | PLF |
| $P_{mh}$ | 1359 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 1: Joists Embedded 4"

### *1st Floor Joists to Grade Level*

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 4 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1298 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 327 | PLF |
| Live Load | $P_L$ | 676 | PLF |
| Eccentricity of Load | e | 2.67 | in |
| Wind Pressure | p | 10.2 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 57 | ft•lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1625 | PLF | |
| Flexural tension stress | $f_t$ | -11.90 | PSI | |
| | | **OK** | **($f_t$ < 40 PSI)** | |

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 132 | ft•lb/ft | |
| Load at mid-height | $P_{mh}$ | 2301 | PLF | |
| Stress from axial load | fa | 25.1 | PSI | |
| Stress from bending | fb | 13.6 | PSI | |
| Slenderness effect | kh/r | 22 | | |
| Allowable comp. stress | Fa | 708 | PSI | for kh/r > 99 |
| | Fa | 67 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 67 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.523 | | |
| | | **OK** | **(Must be less than 1)** | |

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 9880 | PLF |
| Pe/4 | 2470 | PLF |
| $P_{mh}$ | 1625 | PLF |
| | **OK** | |
| | | **(Pmh < 1/4 Pe)** |

## CASE 2: Joists Embedded 3"

### Roof Joists to 2nd Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 382 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 101 | PLF |
| Live Load | $P_L$ | 151 | PLF |
| Eccentricity of Load | e | 3.00 | in |
| Wind Pressure | p | 11.5 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 129 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 483 | PLF | |
| Flexural tension stress | $f_t$ | 8.04 | PSI | |

**OK** **($f_t$ < 40 PSI)**

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 148 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 634 | PLF | |
| Stress from axial load | fa | 6.9 | PSI | |
| Stress from bending | fb | 15.3 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.281 | | |

**OK** **(Must be less than 1)**

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 704 | PLF |
| Pe/4 | 176 | PLF |
| $P_{mh}$ | 483 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 2: Joists Embedded 3"

### 1st Floor Joists to Grade Level

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 4 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1298 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 327 | PLF |
| Live Load | $P_L$ | 676 | PLF |
| Eccentricity of Load | e | 3.00 | in |
| Wind Pressure | p | 10.2 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 61 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1625 | PLF | |
| Flexural tension stress | $f_t$ | -11.44 | PSI | |

**OK** **($f_t$ < 40 PSI)**

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 146 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 2301 | PLF | |
| Stress from axial load | fa | 25.1 | PSI | |
| Stress from bending | fb | 15.0 | PSI | |
| Slenderness effect | kh/r | 22 | | |
| Allowable comp. stress | Fa | 708 | PSI | for kh/r > 99 |
| | Fa | 67 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 67 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.539 | | |

**OK** **(Must be less than 1)**

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 3562 | PLF |
| Pe/4 | 891 | PLF |
| $P_{mh}$ | 1625 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 3: Joists Embedded 2"
### Roof Joists to 2nd Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 382 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 101 | PLF |
| Live Load | $P_L$ | 151 | PLF |
| Eccentricity of Load | e | 3.33 | in |
| Wind Pressure | p | 11.5 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 130 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 483 | PLF | |
| Flexural tension stress | $f_t$ | 8.18 | PSI | |

**OK** **($f_t$ < 40 PSI)**

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 151 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 634 | PLF | |
| Stress from axial load | fa | 6.9 | PSI | |
| Stress from bending | fb | 15.6 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.285 | | |

**OK** **(Must be less than 1)**

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 148 | PLF |
| Pe/4 | 37 | PLF |
| $P_{mh}$ | 483 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 3: Joists Embedded 2"

## 2nd Floor Joists to 1st Floor Joists

### Wall Parameters

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1145 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 214 | PLF |
| Live Load | $P_L$ | 376 | PLF |
| Eccentricity of Load | e | 3.33 | in |
| Wind Pressure | p | 10.2 | PSF |

### Properties

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

### Check for Flexural Tension Stresses

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 133 | ft•lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1359 | PLF | |
| Flexural tension stress | $f_t$ | -1.13 | PSI | |

**OK** **($f_t < 40$ PSI)**

### Check for Compression Stresses

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 185 | ft•lb/ft | |
| Load at mid-height | $P_{mh}$ | 1735 | PLF | |
| Stress from axial load | fa | 19.0 | PSI | |
| Stress from bending | fb | 19.1 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.523 | | |

**OK** **(Must be less than 1)**

### Check for Safety against Buckling

| | | |
|---|---|---|
| Pe | 148 | PLF |
| Pe/4 | 37 | PLF |
| $P_{mh}$ | 1359 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 3: Joists Embedded 2"
## 1st Floor Joists to Grade Level

### Wall Parameters

| | | | Units |
|---|---|---|---|
| Wall Height | h | 4 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1298 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 327 | PLF |
| Live Load | $P_L$ | 676 | PLF |
| Eccentricity of Load | e | 3.33 | in |
| Wind Pressure | p | 10.2 | PSF |

### Properties

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

### Check for Flexural Tension Stresses

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 66 | ft•lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1625 | PLF | |
| Flexural tension stress | $f_t$ | -10.97 | PSI | |

**OK** **($f_t$ < 40 PSI)**

### Check for Compression Stresses

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 160 | ft•lb/ft | |
| Load at mid-height | $P_{mh}$ | 2301 | PLF | |
| Stress from axial load | fa | 25.1 | PSI | |
| Stress from bending | fb | 16.5 | PSI | |
| Slenderness effect | kh/r | 22 | | |
| Allowable comp. stress | Fa | 708 | PSI | for kh/r > 99 |
| | Fa | 67 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 67 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.555 | | |

**OK** **(Must be less than 1)**

### Check for Safety against Buckling

| | | |
|---|---|---|
| Pe | 750 | PLF |
| Pe/4 | 188 | PLF |
| $P_{mh}$ | 1625 | PLF |

**NOT ADEQUATE**
**(Pmh < 1/4 Pe)**

## CASE 4: Joists Embedded 1"
### Roof Joists to 2nd Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 382 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 101 | PLF |
| Live Load | $P_L$ | 151 | PLF |
| Eccentricity of Load | e | 3.67 | in |
| Wind Pressure | p | 11.5 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 132 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 483 | PLF | |
| Flexural tension stress | $f_t$ | 8.33 | PSI | |

**OK** **($f_t$ < 40 PSI)**

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 155 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 634 | PLF | |
| Stress from axial load | fa | 6.9 | PSI | |
| Stress from bending | fb | 16.0 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.289 | | |

**OK** **(Must be less than 1)**

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 4 | PLF |
| Pe/4 | 1 | PLF |
| $P_{mh}$ | 483 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 4: Joists Embedded 1"
### 2nd Floor Joists to 1st Floor Joists

**Wall Parameters**

| | | | Units |
|---|---|---|---|
| Wall Height | h | 9 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1145 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 214 | PLF |
| Live Load | $P_L$ | 376 | PLF |
| Eccentricity of Load | e | 3.67 | in |
| Wind Pressure | p | 10.2 | PSF |

**Properties**

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

**Check for Flexural Tension Stresses**

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 136 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1359 | PLF | |
| Flexural tension stress | $f_t$ | -0.82 | PSI | |

**OK** **($f_t$ < 40 PSI)**

**Check for Compression Stresses**

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 193 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 1735 | PLF | |
| Stress from axial load | fa | 19.0 | PSI | |
| Stress from bending | fb | 20.0 | PSI | |
| Slenderness effect | kh/r | 49 | | |
| Allowable comp. stress | Fa | 140 | PSI | for kh/r > 99 |
| | Fa | 60 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 60 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.532 | | |

**OK** **(Must be less than 1)**

**Check for Safety against Buckling**

| | | |
|---|---|---|
| Pe | 4 | PLF |
| Pe/4 | 1 | PLF |
| $P_{mh}$ | 1359 | PLF |

**NOT ADEQUATE**

**(Pmh < 1/4 Pe)**

## CASE 4: Joists Embedded 1"
## 1st Floor Joists to Grade Level

### Wall Parameters

| | | | Units |
|---|---|---|---|
| Wall Height | h | 4 | ft |
| Wall Thickness | t | 7.625 | in |
| Weight of Wall @ Midheight | W | 1298 | PLF |
| Brick Compressive Strength | f'm | 275 | PSI |
| Dead Load | $P_D$ | 327 | PLF |
| Live Load | $P_L$ | 676 | PLF |
| Eccentricity of Load | e | 3.67 | in |
| Wind Pressure | p | 10.2 | PSF |

### Properties

| | | | |
|---|---|---|---|
| Section Modulus | S | 116 | $in^3/ft$ |
| Moment of inertia | I | 443 | $in^4/ft$ |
| Cross-sectional area | A | 91.5 | $in^2$ |
| Radius of gyration | r | 2.2 | in |
| Support constant | k | 1.0 | |
| Modulus of elasticity | $E_m$ | 192500 | PSI |

### Check for Flexural Tension Stresses

| | | | Units | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 70 | ft*lb/ft | (Ignore Live Load) |
| Load at mid-height | $P_{mh}$ | 1625 | PLF | |
| Flexural tension stress | $f_t$ | -10.49 | PSI | |

**OK** **($f_t$ < 40 PSI)**

### Check for Compression Stresses

| | | | | |
|---|---|---|---|---|
| Moment at mid-height | $M_{mh}$ | 174 | ft*lb/ft | |
| Load at mid-height | $P_{mh}$ | 2301 | PLF | |
| Stress from axial load | fa | 25.1 | PSI | |
| Stress from bending | fb | 17.9 | PSI | |
| Slenderness effect | kh/r | 22 | | |
| Allowable comp. stress | Fa | 708 | PSI | for kh/r > 99 |
| | Fa | 67 | PSI | for kh/r <=99 |
| Applicable Value | Fa | 67 | PSI | |
| Allowable bending stress | Fb | 92 | PSI | |
| Unity Equation | | 0.571 | | |

**OK** **(Must be less than 1)**

### Check for Safety against Buckling

| | | |
|---|---|---|
| Pe | 20 | PLF |
| Pe/4 | 5 | PLF |
| $P_{mh}$ | 1625 | PLF |

**NOT ADEQUATE**
**(Pmh < 1/4 Pe)**

## ECCU

See Hanger Options General Notes.

**UPLIFT**

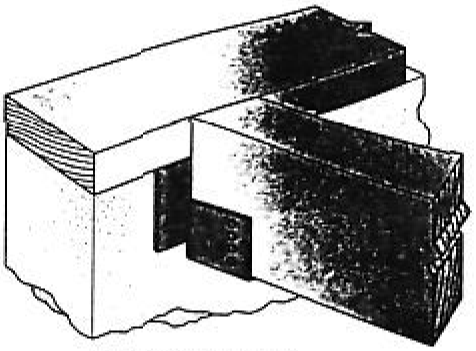
- The ECCU End Column Cap is a modified ECC that provides additional uplift load capacity.
- The ECCU accommodates the same beam and post sizes as the CC.
- ECCU44 and ECCU44ROT have two beam bolts; all other models have 4 beam bolts.
- Request Form T-ECCUP-R2 for complete load information.

## GH

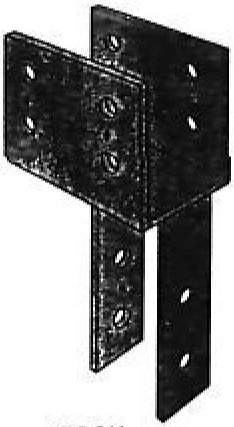
See Hanger Options General Notes.

**SKEWED SEAT**

- GH hangers may be skewed to a maximum of 45°.
- The allowable loads are 100% of the table load.



Typical GH Installation Skewed Right



ECCU
*(except ECCU44)*

## B SERIES

See Hanger Options General Notes.
See also LSU/LSSU.

**SLOPED OR SKEWED**

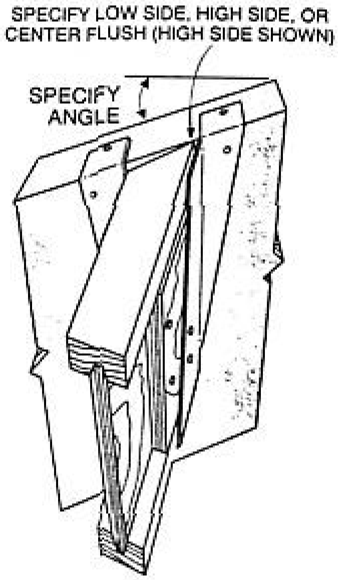
- Web stiffeners are required for I-joist.
- LBV, B, HB series hangers can be skewed to a maximum of 45° and/or sloped to a maximum of 45°.
- HHB, GB, HGB series may be sloped to a maximum of 45°.
- For skews greater than 15°, uplift loads are 0.50 of the table loads.
- Bevel cut the carried beam.
- LBV, B, HB—slope and skew combinations have a maximum allowable download of 0.71 for LBV, 0.73 for B, and 0.58 for HB hangers of the table load.
- For skews only, the maximum allowable download is 0.90 (for LBV hangers), 0.62 (for B and HB hangers) of the table load.
- For sloped only between 0° and 30°, the allowable load is 100% of the table load. For 31° to 45°, the maximum allowable download is 0.70 of the table load for the HGB series and 0.80 for all others.
- All combinations of slope and skew may have more than ⅛" deflection under a full load condition.

**SLOPED TOP FLANGE**

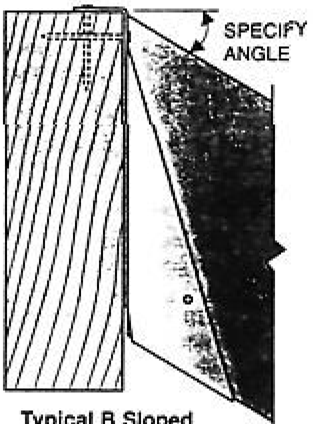
- A top flange may be ordered sloped down left or down right to 35° with or without a sloped and/or skewed seat (see illustration). Reduce allowable table loads using straight-line interpolation (see open/closed W hanger top flange section).

**SADDLE HANGER**

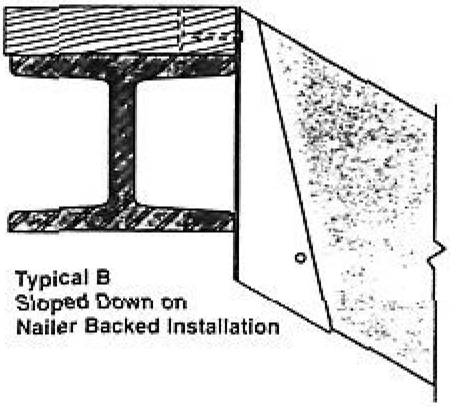
- See B Beam and Purlin Hangers page 54, 72 and 96.



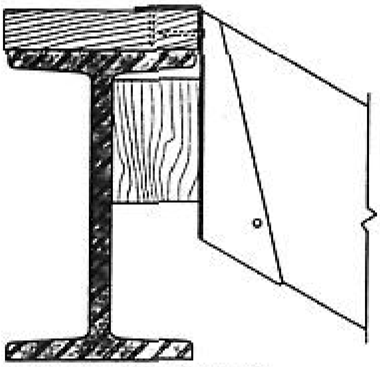

B Hanger Sloped Down and Skewed Left with Sloped Top Flange Installation.



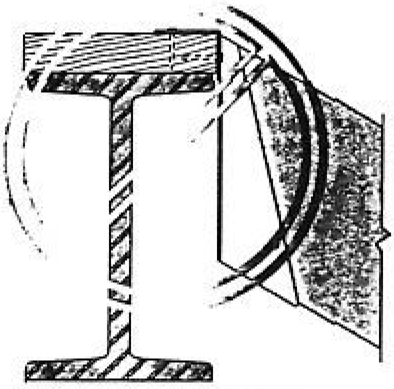

Typical B Sloped Down Installation with Full Backing
*(LBV similar)*



Typical B Sloped Down on Nailer Backed Installation



Typical B Sloped Down on Nailer with Backer Block



B Sloped Down NON-Backed on Nailer is NOT acceptable
*(Contact factory for custom order)*

# HANGER OPTION… GENERAL NOTES

This information applies only to the hange… … Simpson Strong-Tie and installed per our instr… … Some … nations of these options on a single hanger have n… been ev… … **In some cases, combinations of these options cannot be m… tured. A qualified designer must always evaluate each com… including header and joist limitations, before specifying th… …duct.**

Testing is performed using a standardized hanger test m… The joist in the test setup may include the minimum amount of s… stability where appropriate. For example, the sloped down ha… tests are assembled with a joist cut on the lower end to lie flush w… wood member attached with three 8d common toenails. Header an… …er attached structural members are assumed fixed in actual ins… …ons. Horizontal loads induced by sloped joists must be resisted by … members in the structural system.

**MATERIAL:** Gauge may vary from that specified depending on … manufacturing process used. U, HU, HUTF, W and B hangers norm… have single-piece stirrups; occasionally, the seat may be welded. H… configurations, height and fastener schedules may vary from the … depending on the joist size, skew and slope.

**FINISH:** See specific hanger tables. Welded specials: Simpson … paint. Specials that are not galvanized before fabrication can … galvanized after fabrication; specify HDG.

**CODES:** Modified hangers, due to their numerous variations, … on code reports, except U/HU (NER-499).

**LOADS:** For multiple options on the same connector, use the s… lest reduction factor to … lowest design loads.

**TO ORDER:** Use the a…viations below to order specials. The example shows … W410 hanger and ill… …es most available options; most special hangers have only a few of these fe…es.

**INSTALLATION:** • Faste… quantities may be increased beyond the amount specified in the standard hanger table.

- Fill all holes wit… the table-specified fastener types.
- N20A, N20AN an… N54A fasteners are supplied with hangers.
- B, W and GLT hangers for sloped seat installations are assumed backed. To order a custom non-backed hanger, contact factory.
- Bevel-cut the wood member's end for skewed type A hangers; butt-cut wood members for skewed type B hangers.

**WD 410X D30 L20 TFDL20 S=3$\frac{9}{16}$ TF open 20 OSR**

- W = Base Model Series
- D = Saddle
- 410 = Base Model Size
- X = Special
- D = Seat Down (30°) (U = Seat Up)
- L = Skewed Left (20°) R = Skewed Right)
- Top Flange Down Left (20°)
- S = Saddle Width (3$\frac{9}{16}$)
- TF = Top Flange Open (20°)
- Offset Top Flange Right (OSL = Offset Top Flange Left)

| MODEL | SKEWED SEAT (MAXIMUM) | SLOPED SEAT (MAXIMUM) | SKEWED & SLOPED SEAT | SLOPED TOP FLANGE | OPEN TOP FLANGE | CLOSED TOP FLANGE | OFFSET TOP FLANGE | SADDLE HANGER | RIDGE HANGER | CONCEALED FLANGE | UPLIFT | WELDABILITY | NON-BACKED | BEVEL CUT JOIST | SQUARE (BUTT) CUT JOIST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B/BI | 45° | 45° | • | • | | | | • | | | • | • | • | • | |
| EG | 45° | 45° | | | | | | | | | | | | • | |
| GB | | 45° | | | | | | • | | | • | • | | • | |
| GH | 45° | | | | | | | • | | | | | | • | |
| GLS | 50° | 45° | • | • | | | • | • | | | • | • | | • | |
| GLT/GLTV | 50° | 45° | • | • | | | • | | | | • | • | • | • | |
| GLTC | | | | | | | | | | | • | • | | • | |
| HB/HBI | 45° | 45° | • | | | | | • | | | • | • | • | • | |
| HGB | | 45° | | | | | | • | | | • | • | | • | |
| HGLS | 50° | 45° | | • | | | • | • | | | • | • | | • | |
| HGLT/HGLTV | 50° | 45° | | • | | | • | | | | • | • | • | • | |
| HGUS | 45° | | | | | | | | | | | | | • | |
| HHB | | 45° | | | | | | • | | | • | • | | • | |
| HHUS | 45° | 45° | • | | | | | | | | • | | | • | |
| HSUR/L* | 45° | | | | | | | | | | • | | | | • |
| HU | 67½° | 45° | • | | | | | | | • | • | • | | | • |
| HUS | | | | | | | | | | • | | | | • | |
| HUSTF | | | | | | | | | | • | | | | • | |
| HUTF | 45° | 45° | • | | | | | | | • | • | | | | • |
| HW/HWI*** | 84° | 45° | • | • | • | | • | • | • | | | • | • | • | • |
| HWU | 45° | 45° | • | | | | | • | | | • | | | • | |
| LBV** | 45° | 45° | • | • | | | | • | | | • | • | • | • | |
| LEG | 45° | 45° | | | | | • | | | | | | | • | |
| LSU/LSSU | 45° | 45° | • | | | | | | | | • | | | | • |
| MBHA | 45° | | | | | | | | | | | | | | • |
| MEG | 45° | 45° | | | | | • | | | | | | | • | |
| MSC | 45° | 45° | • | | | | | • | | | | • | | | • |
| SUR/L* | 45° | | | | | | | | | | • | | | | • |
| THGB | 45° | 45° | | | | | | | | | | | | | • |
| U | 67½° | 45° | • | | | | | | | | • | | | | • |
| W/WI*** | 84° | 45° | • | • | • | • | • | • | • | | | • | • | • | • |
| WM/WMI | 45° | 45° | • | | | | • | | | | • | | • | • | |
| WMU | | | | | | | | | | | | | | • | |
| WNP/WP/WPI*** | 84° | 45° | • | • | • | • | • | • | • | | | • | • | • | • |
| WPU/WNPU | 45° | 45° | • | | | | | • | | | • | | | • | |

## HANGER OPTIONS MATRIX

See pages 141 to 145 for model options.

**NOTE:** No uplift loads are allowed for welded header attachments.

* Available in 45° only.

**JB/LB cannot be modified, use LBV.

***Available in bevel cut or square cut joist

# W/WNP/HW/WPT/WNPPT/WMPT

See Hanger Options General Notes.

**INSTALLATION:** • Some models are available in Type A (Bevel Cut) and Type B (Butt Cut) styles; all models are available in Type B style. **Check factory when ordering.**
- Bevel-cut the joist for skewed Type A hangers (see illustration). Butt-cut the joist for Type B hangers.
- Hangers with a skew greater than 15° may have all the joist nails on the outside angle.
- Skewed HWs have face nails and require a minimum header depth of 3½".

**HANGER HEIGHT**
- For hanger heights exceeding the joist height by more than 2", the allowable load is 0.50 of the table load. Fillers are acceptable to maintain full load.

**SLOPED AND/OR SKEWED SEAT**
- Non-skewed hangers can carry the design load when the seat slope is within 2° of the joist slope. Designer must check that wood bearing is not limiting.
- W/WNP/HW series may be skewed to a maximum of 84° and/or sloped to a maximum of 45°.
- For slope only, skew only, or slope and skew combinations, the allowable load is 100% of the table load.

**UPLIFT LOADS**
- Hangers can be sloped to 45° and/or skewed 45° at 100% of the uplift load.
- Skew option is only on hangers with "W" 3 9/16" or less.
- For skews greater than 45° there is no uplift load.
- Specify the slope up or down in degrees from the horizontal plane and/or the skew right or left in degrees from the perpendicular vertical plane. Specify whether low side, high side or center of joist will be flush with the top of the header (see illustration).

**SLOPED TOP FLANGE**
- A top flange may be ordered sloped down left or down right to 35° with or without a sloped and/or skewed seat (see illustration). Reduce allowable table loads using straight-line interpolation (see open/closed top flange).

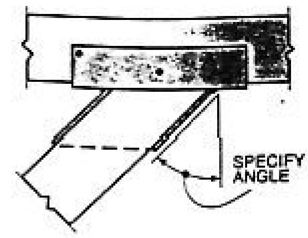
**OFFSET TOP FLANGE**
- The top flange may be offset left or right for placement at the end of a header (see illustration). The allowable load is 0.50 of the table load.
- For skewed and offset top flange hangers, the maximum allowable load is 0.50 of the table load or 2000 lbs., whichever is lower.

**OPEN/CLOSED TOP FLANGE**
- The top flange may be opened more or closed less than the standard 90° (see illustration) to a maximum of 30°, except the HW which can not be closed. Reduce allowable loads using straight-line interpolation.
- Example: For a top flange open 30°, reduce load to [(90-30)/90] x table load.

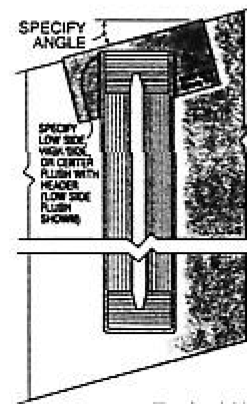
**SADDLE HANGER**
- To order, add D to model and specify S dimension (see illustration).

**RIDGE HANGER**
- Top flange may be sloped to a maximum of 35° to accommodate a ridge (see illustration). Specify angle of the slope. Reduce allowable load using straight-line interpolation. See Open/Closed example.

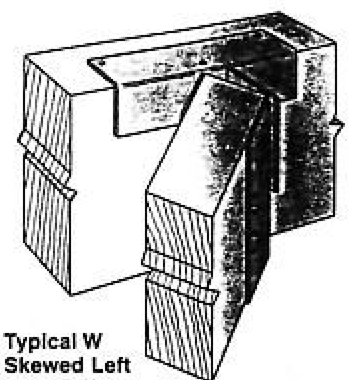
| Model No. | W | H | Fasteners | | Uplift | |
|---|---|---|---|---|---|---|
| | | | Joist | Header | (133) | (160) |
| WNPU | 1 9/16-5½ | 9-18 | 6-10dx1½ | 7-16d | 775 | 855 |
| | | 18½-22½ | 6-10dx1½ | 7-16d | 485 | 485 |
| | | 23-28 | 6-10dx1½ | 7-16d | 315 | 315 |
| WNPUPT | 1 9/16-3 9/16 | 9-18 | 6-10dx1½ | 7-16d | 775 | 855 |
| | | 18½-22½ | 6-10dx1½ | 7-16d | 485 | 485 |
| | | 23-28 | 6-10dx1½ | 7-16d | 315 | 315 |
| HWU | 1 9/16-7½ | 9-18 | 6-10dx1½ | 8-16d | 810 | 855 |
| | | 18½-22½ | 6-10dx1½ | 8-16d | 765 | 765 |
| | | 23-28 | 6-10dx1½ | 8-16d | 635 | 635 |
| | | 28½-32 | 8-10dx1½ | 8-16d | 1005 | 1005 |



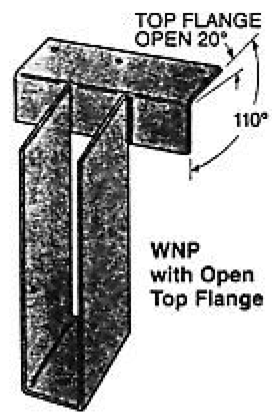

Typical W Top View
Skewed Left
Type A Hanger



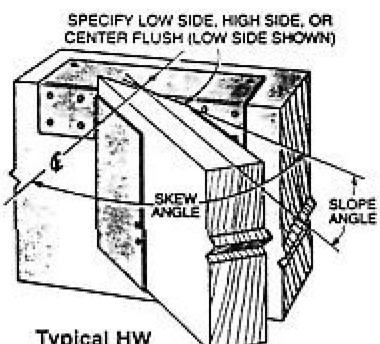

Typical HW
Top Flange Sloped Down Left with Low Side Flush



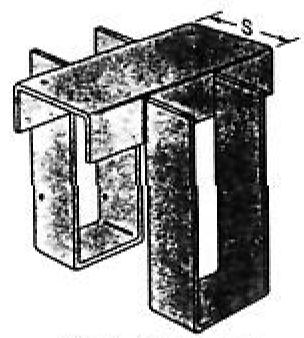
Typical W
Skewed Left
Type B Hanger
(specify A style if required)



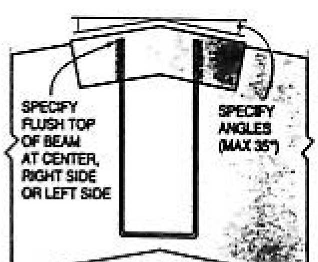

WNP
with Open
Top Flange



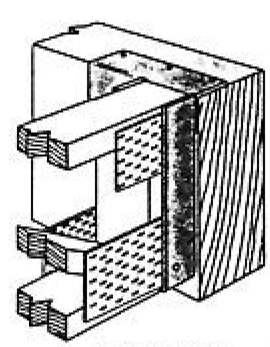

Typical HW
Sloped Down,
Skewed Right with
Low Side Flush Type A Hanger
(joist end must be bevel cut)




WD Saddle Hanger




Typical W
Ridge Installation



Typical WPT
Top Flange Offset Left

## U/HU

See Hanger Options General
**Not all Slope and Skew Con  ...ons are available.**
CODE: BOCA, ICBO, SBCCI N...

**SLOPED AND/OR SKEWED**

- For low-cost, code-rec...ed 45° skews, see SUR/SUL and HSUR/HSUL. See also ...SSU connectors.
- U/HU may be skewed t... a maximum of 67½° and sloped to a maximum of 45°.
- For all options, uplift loads are 0.75 of table loads.
- For combined slopes and skews, the maximum allowable download is 0.80 of the table load.
- For slope only or skew only, the allowable download is 100% of the table load.

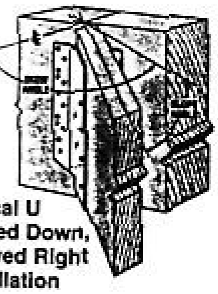
**STRAIGHT OR CONCEALED FLANGE**

- HU is available with the A flanges straight at 100% of the table loads if W ≥ 3½".
- If W < 3", use N10 nails at 0.64 of the table load.
- If W ≥ 3", use 10d nails at 0.84 of the table load.
- HU is available with A flanges concealed, provided the W dimension is 2⁹⁄₁₆" or greater, at 10...% of the table load.
- HU is available with one flange concealed when the W dimension is less than 2⁹⁄₁₆" at 100...% of the table load.
- For skewed only hangers the flange on the acute side can be concealed at 100% of the table load. **Consult factory for skew**

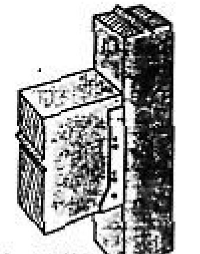
...anges can be concealed at 100% of

...the flange on the acute side can
...d. **Consult the factory for**

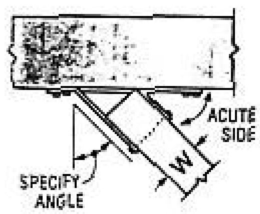
...s end grain, the allowable
...oad is 0.67 of the table load.



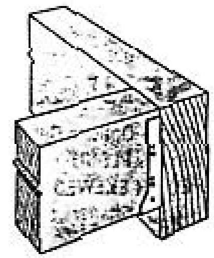
Typical U Sloped Down, Skewed Right Installation

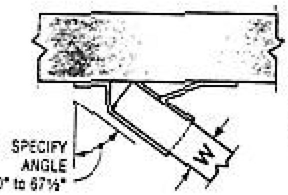


Typical HUC Installation on a Post




Top View U Hanger Skewed Right






Top View U Hanger Skewed Right > 50

Typical HUC Installed on a Beam

## HUTF

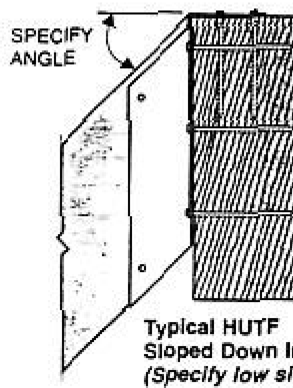
See Hanger Options General Notes.

**SLOPED AND/OR SKEWED SEAT**

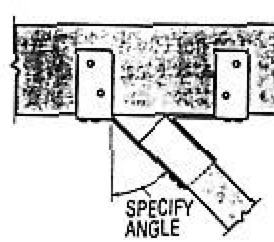
- HUTF can be skewed to a maximum of 45° or sloped to a maximum of 45°. HUTF can be skewed and sloped down, provided W ≥ 2⁵⁄₁₆". Hangers with a skew greater than 15° may have all the joist nailing on the outside angle.
- For the skewed-only HU34TF, HU24-2TF and HU44TF, the allowable loads are 0.50 of the table load. All other models have a maximum allowable load of 0.60 of the table loads.
- For skews greater than 15°, uplift loads are 0.75 of the table loads.
- For sloped and skewed hangers, the allowable loads are 0.70 of the table loads.
- For sloped down only hangers, allowable load is 0.78 of the table load.

**CONCEALED FLANGE**

- HUTF is available with A flanges concealed provided the W dimension is 2⁹⁄₁₆" or greater, at 0.85 of the table load. No skew options available.




Typical HUTF Sloped Down Installation *(Specify low side, high side, or center flush)*




Top View HUTF Hanger Skewed Right

## HGUS/HHUS

See Hanger Options General Notes.

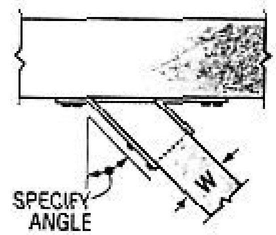
**SLOPED AND/OR SKEWED SEAT**

- HHUS hangers can be skewed to a maximum of 45° and/or sloped to a maximum of 45°.
- HHUS skew only, maximum allowable download is 0.85 of the table load.
- For sloped only or sloped and skewed hangers, the maximum allowable download is 0.65 for HHUS.
- Not all slope and skew combinations are available; consult the factory for information.
- The joist must be bevel-cut to allow for double shear nailing.
- Uplift loads for sloped/skewed conditions are 0.72 of the table load, not to exceed 2475 lbs for HHUS hangers.

HGUS hangers can be skewed only to a maximum of 45°. Allowable loads are:

| Models | Down Load | Uplift |
|---|---|---|
| 2x | 0.75 of table load | 0.84 of table load |
| 2-2x, 3-2x | 0.45 of table load | 0.50 of table load |

- Square or bevel cut is acceptable.




Top View HHUS Hanger Skewed Right (joist must be bevel cut) All joist nails installed on the outside angle.

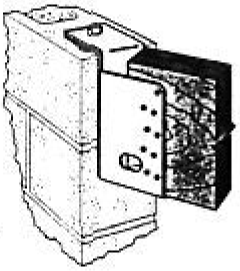
# HANGER OPTIONS

## MBHA

See Hanger Options General Notes.

SKEWED SEAT

- Seat can be skewed at 45° only. The maximum allowable download is 3495 lbs and 1585 lbs uplift for Height 7.25. For all other models, use the table listed download and uplift of 2390 lbs.



Typical MBHA Installation

## LEG/MEG/EG

See Hanger Options General Notes.

SKEWED SEAT—TOP FLANGE MODELS ONLY

- The LEG/MEG/EG series can be skewed up to 45°. The maximum allowable load is 10,000 lbs. for LEG and MEG, 14,250 lbs. for EG.

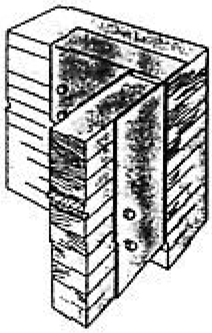
SLOPED SEAT—TOP FLANGE MODELS ONLY

- The LEG/MEG/EG series can be sloped up to 45°. The maximum allowable load is 9665 lbs; see illustration.

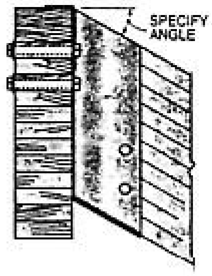
NO SLOPED AND SKEWED COMBO AVAILABLE.

OFFSET TOP FLANGE

- The LEG/MEG top flange may be offset left or right for placement at the end of a header (min W = 3, min H = 11¼) (see illustration). The maximum allowable load is 5665 lbs.
- No skews allowed on offset hangers.



Typical LEG/MEG Top Flange Offset Left




Typical LEG/MEG/EG Sloped Down Installation

## WM/WMI/WMU

See Hanger Options General Notes.

INSTALLATION: • Bevel-cut the joist for skewed hangers (see illustration).

HANGER HEIGHT

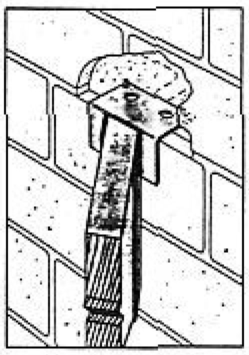
- For hanger heights exceeding the joist height, the allowable load is 0.50 of the table load.

SLOPED AND/OR SKEWED SEAT

- WM/WMI/WMUs may be skewed and/or sloped to 45° maximum.
- The allowable load is 100% of the table load.

OFFSET TOP FLANGE

- The top flange may be offset left or right for placement at the end of a header. The allowable load is 0.50 of the table roof load.



Typical WM Sloped Down, Skewed Right Block Wall Installation

| Model No. | W | H | Fasteners | | | Uplift (133 & 160) |
|---|---|---|---|---|---|---|
| | | | Joist | Top | Face | |
| WMU | 1½ to 7½ | 9 to 18 | 6-10dx1½ | 2-16d DPLX | 4-¼x1" Masonry | 660 |
| | 1½ to 7½ | 18½ to 22½ | 6-10dx1½ | 2-16d DPLX | 4-¼x1" Masonry | 660 |
| | 1½ to 7½ | 23 to 28 | 6-10dx1½ | 2-16d DPLX | 4-¼x1" Masonry | 625 |

## MSC

See Hanger Options General Notes.

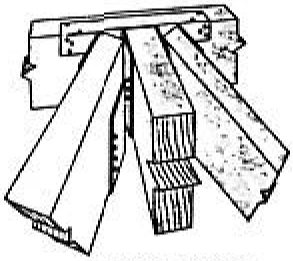
INSTALLATION: • Distribute the total load evenly about the centerline to avoid eccentric loading.

- Fasten all built-up members together as one unit.
- **Net height will be calculated based on specified valley rafter depth and slope by the factory unless noted otherwise.**

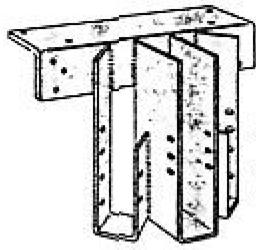
SLOPED AND/OR SKEWED VALLEYS

- The valley rafter stirrups can be sloped & skewed to 45°.
- The total design load of the hanger is split between the ridge rafter (20%) and each valley rafter (40%).
- For two valley rafter connections with no ridge rafter member, divide the total load by two for each valley rafter load.

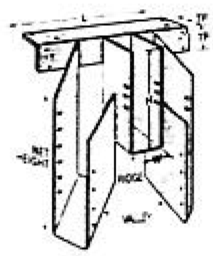
CODE: BOCA, ICBO, SBCCI NER-432.



Typical MSC4 Installation



MSC1.81 with Valley rafter skewed 45 , and sloped 0




MSC4 with Valley Rafters sloped and skewed 45

| Model No. | Dimensions | | | | Fasteners | | Hips | | Allowable Loads (100 & 125) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | W | H (Min) | TF | L | Header | Joist | Max. Skew | Max. Slope | Hip | Jack | Total |
| MSC2 | 1 9/16 | 5½ | 2⅜ | 12 | 10-16d | 18-10dx1½ | 45° | 0° | 2535 | 1265 | 6335 |
| | | | | | | 26-10dx1½ | | 45° | 2010 | 1005 | 5025 |
| MSC1.81 | 1 13/16 | 5½ | 2⅜ | 12 | 10-16d | 18-10dx1½ | 45° | 0° | 2535 | 1265 | 6335 |
| | | | | | | 26-10dx1½ | | 45° | 2010 | 1005 | 5025 |
| MSC4 | 3 9/16 | 7½ | 2⅜ | 18 | 10-16d | 18-10d | 45° | 0° | 3335 | 1665 | 8335 |
| | | | | | | 26-10d | | 45° | 3335 | 1665 | 8335 |

1. For valley rafters with combined slope and skews between 0° and 45°, use 45° slope and skew loads.
2. Use total load when there is no center member.
3. MSC4 is available in 3⅛" Glulam width.
4. MSC1.81 and MSC2 available in saddle conditions (order MSCDI.81)

# ANSI/TPI 1-1995 NOTE

ANSI/TPI 1-1995 is the *National Design Standard for Metal Plate Connected Wood Truss Construction.* Within this standard, the design criteria and design responsibilities for all truss-to-truss connections are defined. One section of this standard includes a requirement to check the cross grain tension value of the lumber in the carrying (girder) member at each face mount hanger connection.

Although the ANSI/TPI 1-1995 standard does not affect the carrying capacity of our connectors, the cross grain tension of the lumber may be limiting. This calculated value for the lumber is controlled by the lumber cross-section (number of plys), wood species and the location of the upper most fastener in the face mount hangers. Some face mount truss hanger connections will have reduced allowable load values when this standard is applied. See Simpson Strong-Tie's ANSI/TPI load tables on pages 146-151.

## Connections Unaffected by ANSI/TPI 1-1995

- Top flange hangers such as the PF, HUTF, WPT series, and MSCPT are not affected.
- THA adjustable truss hangers are not affected provided the hanger is wrapped over the top of the truss chord and is fastened to either the top or back of the chord.
- Bolted connections such as our THGB series, and THG2AR/L are not affected when attached to a vertical web member.
- Connectors attached to a solid sawn header, glulam beam or composite wood product such as an LVL, PSL and LSL are not affected.
- Miscellaneous connectors such as the VPA, HRC, HCP, LTS, MTS, HTS, TBE, TC, ETA, META, HHETA Hurricane Ties and angles are not affected.

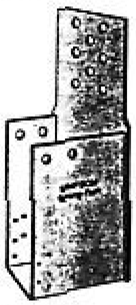
# HANGER OPTIONS

## THGB

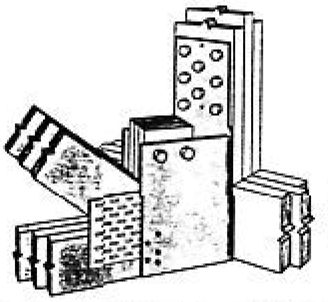
See Hanger Options General Notes.

**SLOPED OR SKEWED SEAT**

- The maximum allowable load for slope is .87 of the table load.
- The maximum allowable load for skew is .74 of the table load.



THGBH3SKL



Typical THGB Installation Skewed Left

## GLT/HGLT/GLS/HGLS/GLTC/GLTV/HGLTV

See Hanger Options General Notes.

**INSTALLATION:** • Bevel-cut the carried beam for skewed hangers.

**HANGER HEIGHT**

- For hangers exceeding the joist height by 2", allowable load is 50% of the table roof load.

**SLOPED AND/OR SKEWED SEAT**

- GLT/HGLT and GLS/HGLS series may be skewed to a maximum of 50° or sloped to a maximum of 45°.
- For skews greater than 15°, multiply the table uplift load by 0.50.
- For sloped only, the maximum allowable load is 6500 lbs. for the GLT/GLS, 9165 lbs. for the HGLT/HGLS.
- For skewed only, the maximum allowable load is 6550 lbs. for the GLT/GLS, 7,980 lbs. for the HGLT/HGLS. The deflection at full loading may reach ¼".
- Sloped and skewed GLT/GLS configurations have a maximum allowable load of 5500 lbs. **Sloped and skewed combinations are not allowed for the HGLT/HGLS.**

**SLOPED TOP FLANGE**

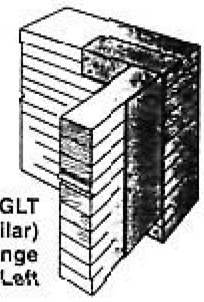
- A top flange may be sloped down left or down right to 30° with or without a sloped and/or skewed seat (see illustration). Reduce allowable table loads using straight-line interpolation.

**OFFSET TOP FLANGE**

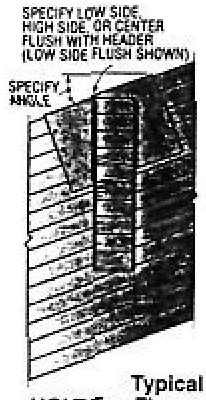
- The top flange may be offset left or right for placement at the end of a header. The maximum allowable load is 0.50 of the table roof load for the GLT/GLS, and 0.45 for the HGLT/HGLS.
- For skewed and offset top flange hangers, the maximum allowable load is 3500 lbs.

**MODIFIED FOR UPLIFT CAPACITY**

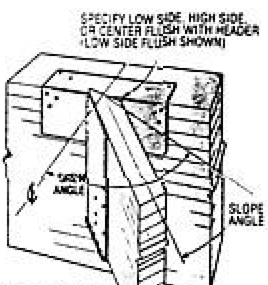
- The 3 gauge GLTC is a modified GLT with enclosed stirrup and backing plate for higher uplift conditions.
- First attach the GLTC to the joist. Then lift the joist and hanger into place.
- The maximum allowable loads are 3660 lbs uplift and 7000 lbs download.



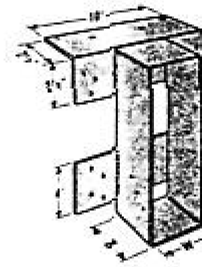
Typical GLT (HGLT similar) Top Flange Offset Left




Typical HGLT Top Flange Sloped Down Left with Low Side Flush




Typical GLT Sloped Down, Skewed Right with Low Side Flush



GLTC

# CUSTOM STEEL PLATES

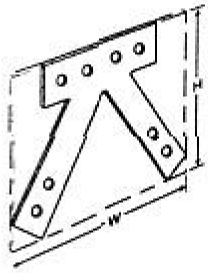
Simpson makes a variety of flat and bent steel shapes, which include gusset plates for heavy timber trusses, custom ornamental shapes and retaining plates.

**MATERIAL:** 3 gauge maximum

**FINISH:** Galvanized, Simpson black or gray paint, stainless steel.

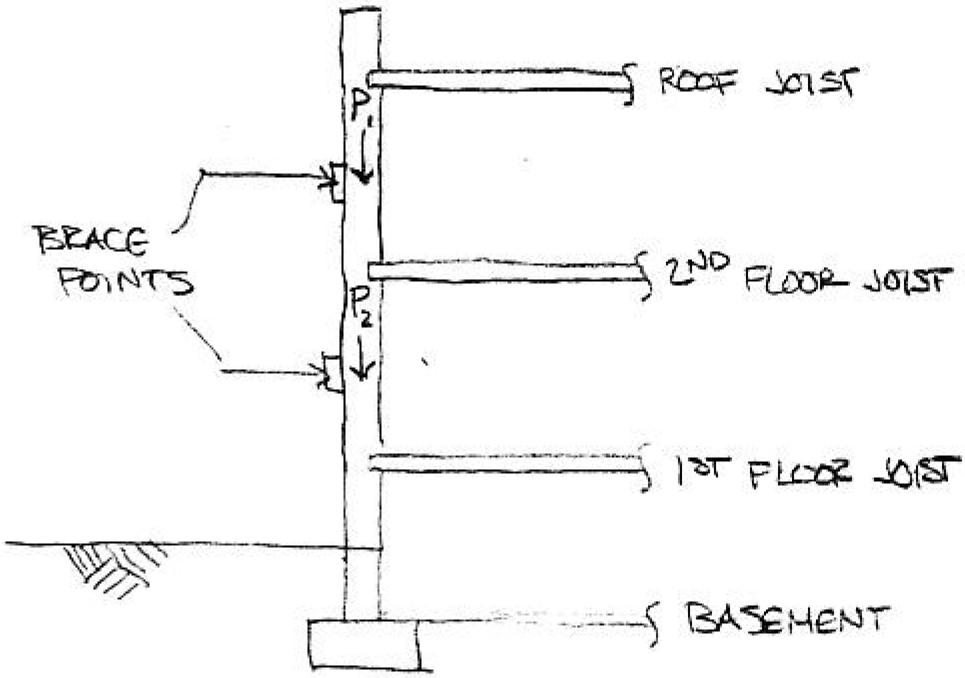
**TO ORDER:** • Supply a CAD drawing in DXF format with complete details of hole shapes, hole sizes, and hole patterns (approx. 1⁄16" tolerance), scale 1:1.

- Total plate shape and size up to max. dimensions of 48" x 48" (approx. 1⁄16" tolerance).
- Simpson does not provide product engineering or load values for Custom Steel Plates.
- Pricing is based on "envelope" size of requested steel shape. Contact Simpson for information.




"W" and "H" indicate the envelope size of the steel shape.

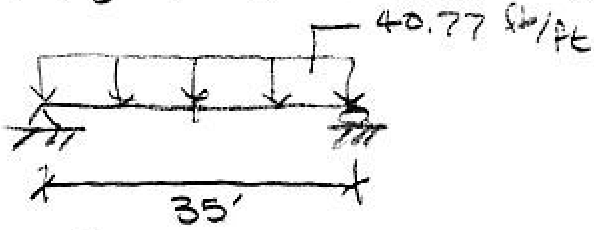
Ansi / TPI

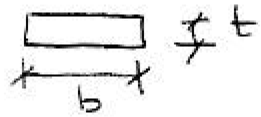



$P_1 = 483\ ^{lb}/_{ft}$ $\qquad$ $P_2 = 1359\ ^{lb}/_{ft}$

BRACING - 2ND FLOOR TO 1ST FLOOR

$3\%\, P_2 = .03(1359\ ^{lb}/_{ft}) = 40.77\ ^{lb}/_{ft}$




$\Delta = \dfrac{5wL^4}{384EI}$

SERVICABILITY DEFLECTION, $\Delta = 0.007h$

$\Delta = .007(9' \times 12''/') = 3/4''$

$I_{req'd} = \dfrac{5(40.77\ ^{lb}/_{ft})(35 \times 12'')^4}{.75''(384)(29 \times 10^6\ PSI)}\left(\dfrac{1'}{12''}\right) = 63\ in^4$

$I = \dfrac{bt^3}{12}$

RETROFIT: STEEL BARS/PLATES (Z) OK CONSULTANTS

POSSIBLE SECTIONS ($I_{req'd}$ = 63 $in^4$)

| t (") | b (") | $I_{prov.}$ ($in^4$) | A ($in^2$) |
|---|---|---|---|
| 2 | 94 1/2 | 63 | 189 |
| 2.5 | 48 1/2 | 63 | 121 |
| 3 | 28 | 63 | 84 |
| 3.5 | 17 3/4 | 63 | 62 |
| 4 | 12 | 64 | 48 |
| 4.5 | 8 1/4 | 63 | 37 |
| 5 | 6 | 63 | 30 |
| 5.5 | 4 1/2 | 62 | 25 |
| 6 | 3 1/2 | 63 | 21 |

TRY t = 4" + b = 12" $\quad F_y = 36^{ksi} \quad S = \frac{bt^2}{6} = 32 \, in^3$

CHECK BENDING

$M_{req'd} = \frac{wL^2}{8} = \frac{40.77 (35)^2}{8} = 6.24^{k \cdot ft}$

$F_b = \frac{M}{S} = \frac{6.24^{k ft}}{32 \, in^3} \left( \frac{12"}{1} \right) = 2.34$ KSI

$f_b = 0.66 F_y = 0.66 (36^{ksi}) = 24 KSI >>> 2.34^{ksi} \therefore \underline{\underline{O.K.}}$

CHECK SHEAR

REACTION $= \frac{wL}{2} = \frac{40.77(35)}{2} = .714^k = V_{MAX}$ (CONSERVATIV

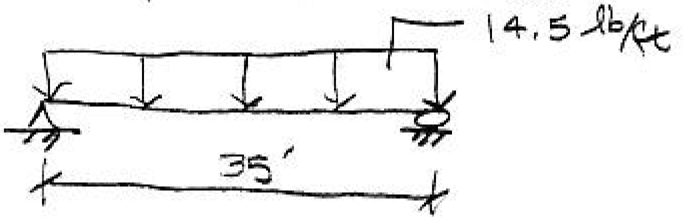
$F_v = .4 F_y = .4 (36 \text{ KSI}) = 14$ KSI

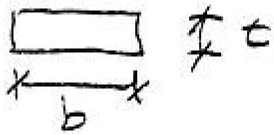
$\tau = \frac{3V}{2A} = \frac{3(.714^k)}{2(4")(12")} = 0.022 \text{ KSI} <<< 14 \text{ KSI} \therefore \underline{\underline{O.K}}$

RETROFIT: STEEL BARS/PLATES (3) OK CONSULTANTS

## BRACING BTWN. ROOF + 2ND FLOOR

$3\% P_1 = .03(483 \text{ lb/ft}) = 14.5 \text{ lb/ft}$




$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(14.5 \text{ lb/ft})(35' \times 12''/')^4}{.75(384)(29 \times 10^6 \text{ PSI})}\left(\frac{1'}{12''}\right) = 23 \text{ in}^4$$

$$I = \frac{bt^3}{12} = 23 \text{ in}^4$$

POSSIBLE SECTIONS

| t ('') | b ('') | $I_{prov}$ (in⁴) | A (in²) |
|---|---|---|---|
| 2 | 34 1/2 | 23 | 69 |
| 2.5 | 17 3/4 | 23 | 44 |
| 3 | 10 1/4 | 23 | 31 |
| 3.5 | 6 1/2 | 23 | 23 |
| 4 | 4 1/2 | 24 | 18 |
| 4.5 | 3 | 23 | 14 |
| 5 | 2 1/4 | 23 | 11 |

TRY $t = 4''$, $b = 4\frac{1}{2}''$

$$S = \frac{bt^2}{6} = \frac{(4\frac{1}{2})(4)^2}{6} = 12 \text{ in}^3$$

CHECK BENDING

$$M = \frac{wL^2}{8} = \frac{14.5(35)^2}{8} = 2.22^{\text{ k}\cdot\text{ft}}$$

$$f_b = \frac{M}{S} = \frac{2.22^{\text{ k}\cdot\text{ft}}}{12 \text{ in}^3}\left(\frac{12''}{'}\right) = 2.22 \text{ KSI}$$

$$F_b = .66F_y = .66(36 \text{ KSI}) = 24 \text{ KSI} \gg 2.22 \text{ KSI}$$

$\therefore$ O.K.

RETROFIT STEEL BARS/PLATES (4) C/K CONSULTANTS

CHECK SHEAR:

$F_v = .4 F_y = .4 (36\text{ KSI}) = 14\text{ KSI}$

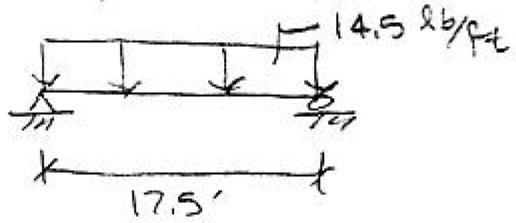
$V_{MAX}$ = REACTION = $\frac{wL}{2} = \frac{14.5\ lb/ft\ (35')}{2} = 254\ lb$
(CONSERVATIVE)

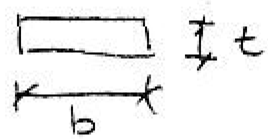
$\tau = \frac{3V}{2A} = \frac{3(.254^k)}{2(4'')(4\frac{1}{2}'')} = 0.02\text{ KSI} << 14^{KSI}$ ∴ O.K.

RETROFIT: STEEL PLATE (2 SECTIONS)    OK CONSULTANTS

BRACING BTWN. ROOF + 2ND FLOOR

$3\%\ P_1 = 14.5\ ^{lb}/_{ft}$




$\Delta = \frac{5wL^4}{384EI} = 3/4''$

$I_{req'd} = \frac{5(14.5\ ^{lb}/_{ft})(17.5' \times 12''/_{'})^4}{.75''(384)(29 \times 10^6\ PSI)} \left(\frac{1'}{12''}\right) = 2\ in^4 = \frac{bt^3}{12}$

POSSIBLE SECTIONS

| t (") | b (") | I, prov (in⁴) | A (in²) |
|---|---|---|---|
| 1 | 24 | 2 | 24 |
| 1 1/4 | 12 1/4 | 2 | 15 |
| 1 1/2 | 7 1/4 | 2 | 11 |
| 1 3/4 | 4 1/2 | 2 | 8 |
| 2 | 3 | 2 | 6 |
| 2 1/4 | 2 1/4 | 2 | 5 |
| 2 1/2 | 1 1/2 | 2 | 4 |
| 2 3/4 | 1 1/4 | 2 | 3 |
| 3 | 1 | 2 | 3 |

TRY $t = 3'' + b = 1''$    $S = \frac{bt^2}{6} = 1.5\ in^3$

CHECK BENDING

$M = \frac{wL^2}{8} = \frac{14.5(17.5)^2}{8} = 0.56\ ^{k \cdot ft}$    $F_b = .66 F_y = 33\ KSI$

$f_b = \frac{M}{S} = \frac{.56\ ^{k \cdot ft}}{1.5\ in^3}\left(\frac{12''}{1'}\right) = 4.5\ KSI < 33\ KSI \therefore$ O.K.

CHECK SHEAR

$F_v = .4 F_y = 20\ KSI$    $V_{MAX} = \frac{wL}{2} = \frac{14.5(17.5)}{2} = .13^k$

$\tau = \frac{3V}{2A} = \frac{3(.13^k)}{2(3\ in^2)} = .07\ KSI < 20\ KSI \therefore$ O.K.

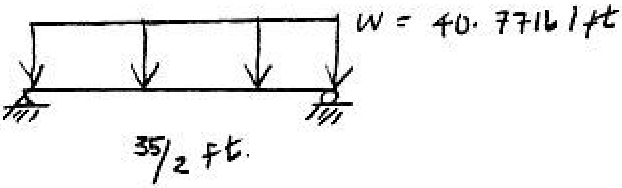
RETROFIT: STEEL BARS/PLATES

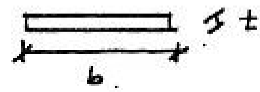
OK CONSULTANTS

→ UTILIZING 2 BARS/PLATES @ $L/2$ = $17\frac{1}{2}$ ft

→ BRACING - $2^{ND}$ FLOOR TO $1^{ST}$ FLOOR

$3\% P_2 \cdot (0.03)(1359 \text{ lb/ft}) = 40.77 \text{ lb/ft}$




$$\Delta = \frac{5WL^4}{384EI}$$

→ SERVICABILITY DEFLECTION, $\Delta = 0.007h$

$\Delta = 0.007(9 \times 12 \text{ in})$
$= 0.75$ in.

$$I_{req} = \frac{(5)(40.77)(17.5 \times 12)^4}{(0.75)(384)(29 \times 10^6)} \times (1/12) = 3.96 \approx 4 \text{ in}^4$$

$$I = bt^3/12$$

→ POSSIBLE SECTIONS ($I_{req} = 4 \text{ in}^4$)

| t (in) | b (in) | $I_{prov}$ (in⁴) | A (in²) |
|---|---|---|---|
| 2 | 6 | 4 | 12 |
| 2 ½ | 3 | 4 | 7 ½ |
| 3 | 1 7/8 | 4.2 | 5 5/8 |
| 4 | 3/4 | 4 | 3 |

→ TRYING $t = 2\frac{1}{2}''$ $b = 3''$

$F_y = 50$ ksi

$S = bt^2/6 = (3)(2.5^2)/6 = 3\frac{1}{8} \text{ in}^3$

→ CHECK BENDING

$M_{req} = WL^2/8 = 40.77(17.5^2)/8 = 1.56$ ft-kip

$F_b = M/S = 1.56 / (3 1/8) \times 12 = 6$ ksi.

$F_b = 0.66 F_y$
$= 0.66 \times 50$
$= 33$ ksi $>>> 6$ ksi

$F_{b_{prov}} >>> F_{b_{req.}}$ $\therefore$ ok!

→ CHECK SHEAR

REACTION = $WL/2$

$= 40.77 \times 17\ 5/2 = 0.36^k = V_{MAX}$ (conservative)

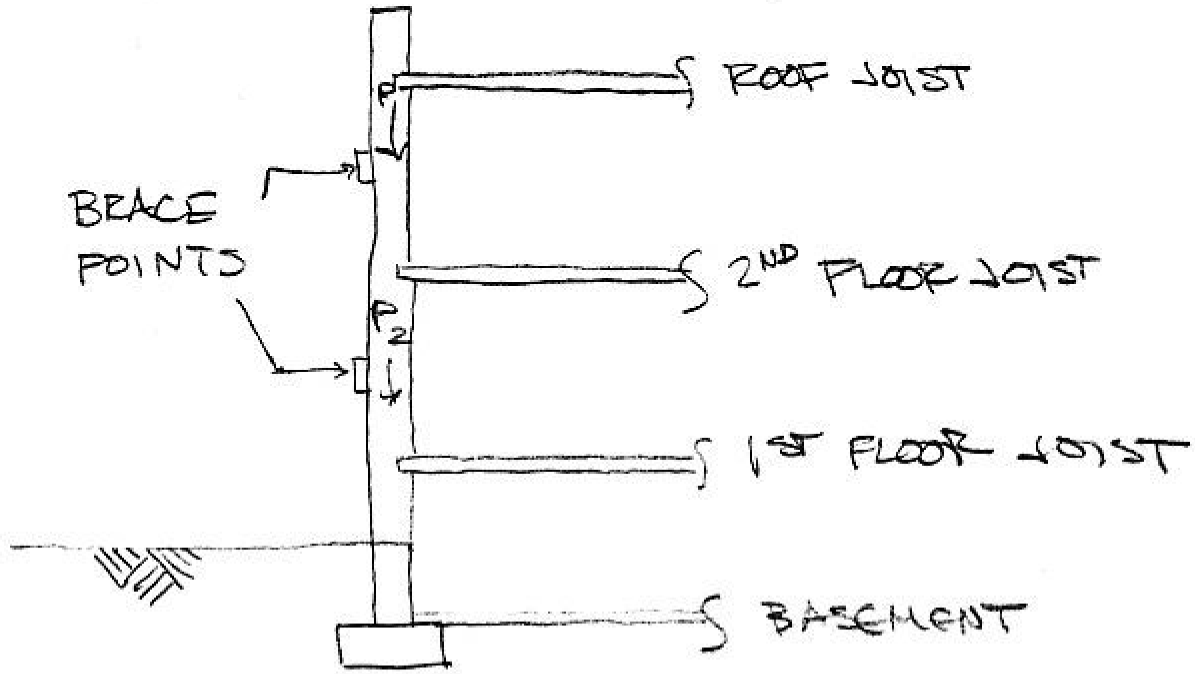
$F_v = 0.4 F_y$
$= (0.4)(50)$
$= 20$ ksi

$\tau = \frac{3V}{2A}$

$= \frac{(3)(0.36)}{(2)(2 1/2 \times 3)}$

$= 0.072$ ksi $<<< 20$ ksi $\therefore$ ok!

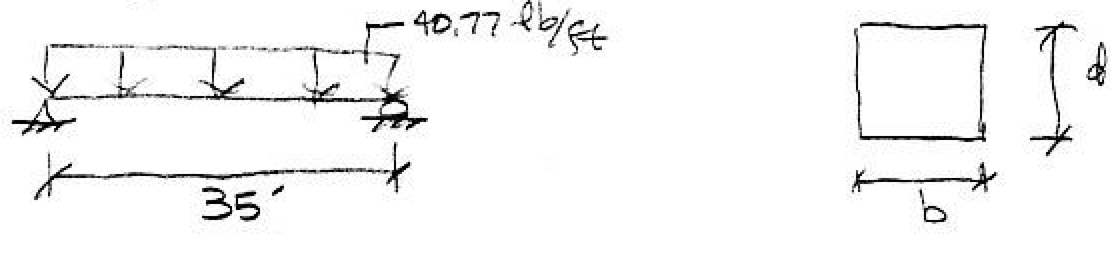
2ND 1/2 SAME AS ABOVE




$P_1 = 483$ lb/ft    $P_2 = 1359$ lb/ft

<u>BRACING BTWN. 2ND FL + 1ST FL</u>

$3\% P_2 = 40.77$ lb/ft




$$\Delta = \frac{5wL^4}{384EI}$$

SERVICABILITY $\Delta = .007h = 3/4''$

<u>TRY DOUGLAS FIR, SELECT STRUCTURAL</u>

$E = 1{,}900{,}000$ PSI

$F_b = 1500$ PSI

$F_v = 95$ PSI

$$I_{req'd} = \frac{5(40.77\,lb/ft)(35' \times 12''/')^4}{(.75'')(384)(1.9\times10^6\,psi)}\left(\frac{1'}{12''}\right) = 966\,in^4 = \frac{bd^3}{12}$$

POSSIBLE SIZES

| d (") | b (") | $I_{prov}$ ($in^4$) |
|---|---|---|
| 4 | 181 | 965 |
| 4½ | 127 | 965 |
| 5 | 93 | 969 |
| 5½ | 70 | 971 |
| 6 | 54 | 972 |
| 6½ | 42 | 962 |
| 7 | 34 | 972 |
| 7½ | 28 | 984 |
| 8 | 23 | 981 |
| 8½ | 19 | 972 |
| 9 | 16 | 972 |
| 9½ | 13½ | 965 |
| 10 | 11½ | 958 |
| 10½ | 10 | 965 |

TRY 10½" × 10" SECTION

CHECK BENDING: $M' = F_b' S$

$F_b' = F_b C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$

ADJUSTMENT FACTORS:

$C_D = 0.9$ (PERMANENT DURATION)

$C_M$ ✓ $C_F$ ✓ $C_i$ ✓ $C_f$ ✓

$C_t$ ✓ $C_V$ ✓ $C_r$ ✓ ALL OTHER ADJUSTMENT

$C_L$ ✓ $C_{fu}$ ✓ $C_c$ ✓ FACTORS = 1.0

$$S = \frac{bd^2}{6} = \frac{10(10\tfrac{1}{2})^2}{6} = 184\,in^3$$

$$M' = 1500\,psi(.9)(184\,in^3)\left(\frac{1'}{12''}\right) = 20.7^{k\cdot ft}$$

$$M_{req'd} = \frac{wL^2}{8} = \frac{40.77\,lb/ft\,(35')^2}{8} = 6.24^{k\cdot ft} << 20.7^{k\cdot ft}$$

$\therefore$ O.K.

CHECK SHEAR:

$$V' = \frac{2F_v'bd}{3}$$

$F_v' = F_v C_D C_M C_i C_H$

$F_v = 95$ PSI

$C_D = 0.9$ (PERMANENT DURATION)

$C_H = 2.0$ (NO SPLITS / SHAKES)

$C_M = C_i = 1.0$

$F_v' = 95(.9)(2) = 171$ PSI

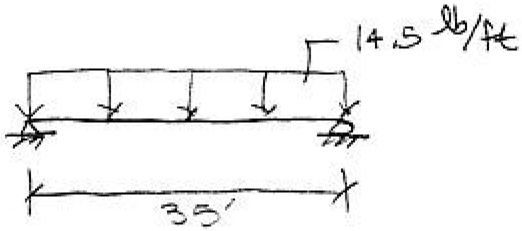
$V' = 2(171 \text{ PSI})(10\tfrac{1}{2}")(10")/3 = 11.97^k$

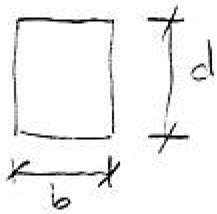
$V_{req'd}$ = REACTION $= \frac{wL}{2}$ (CONSERVATIVE)

$= 40.77(36)/2 = .734^k \lll 11.97^k$ $\therefore$ O.K.

## BRACING BTWN ROOF + 2ND FL

$3\% P_1 = 14.5 \text{ lb/ft}$




$$\Delta = \frac{5wL^4}{384EI}$$

SERVICABILITY $\Delta = 3/4''$

$$I_{req'd} = \frac{5(14.5 \text{ lb/ft})(35' \times 12''/')^4}{(.75)(384)(1.9 \times 10^6 \text{ PSI})}\left(\frac{1'}{12''}\right) = 344 \text{ in}^4 = \frac{bd^3}{12}$$

POSSIBLE SIZES:

| d (") | b (") | $I_{prov}$ (in$^4$) |
|---|---|---|
| 3 | 153 | 344 |
| 3 1/2 | 96 | 343 |
| 4 | 64 1/2 | 344 |
| 4 1/2 | 45 1/2 | 346 |
| 5 | 33 | 344 |
| 5 1/2 | 25 | 346 |
| 6 | 19 | 342 |
| 6 1/2 | 15 | 343 |
| 7 | 12 | 343 |
| 7 1/2 | 10 | 351 |
| 8 | 8 | 341 |

TRY 8" × 8" SECTION

CHECK BENDING

$M' = F_b' S$

$F_b' = F_b C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$

ADJUSTMENT FACTORS:

$C_D = 0.9$ (PERMANENT DURATION)

$C_M$ ✓    $C_f$ ✓    $C_i$ ✓    $C_f$ ✓

$C_t$ ✓    $C_V$ ✓    $C_c$ ✓    ALL OTHER ADJUSTMENT FACTORS = 1.0

$C_L$ ✓    $C_{fu}$ ✓    $C_r$ ✓

$$S = \frac{bd^2}{6} = \frac{8(8)^2}{6} = 85.3 \text{ in}^3$$

$$M' = 1500 \text{ PSI}(.9)(85.3 \text{ in}^3) = 9.6^{k \cdot ft}$$

$$M_{req'd} = \frac{wL^2}{8} = \frac{14.5(35)^2}{8} = 2.22^{kft} < 9.6^{k \cdot ft} \therefore \underline{\text{O.K.}}$$

CHECK SHEAR:

$$V' = \frac{2F_V' bd}{3}$$

$$F_V' = F_V C_D C_M C_i C_H$$

$C_D = 0.9$ (PERMANENT DURATION)

$C_H = 2.0$ (NO SPLITS / SHAKES)

$C_M = C_i = 1.0$

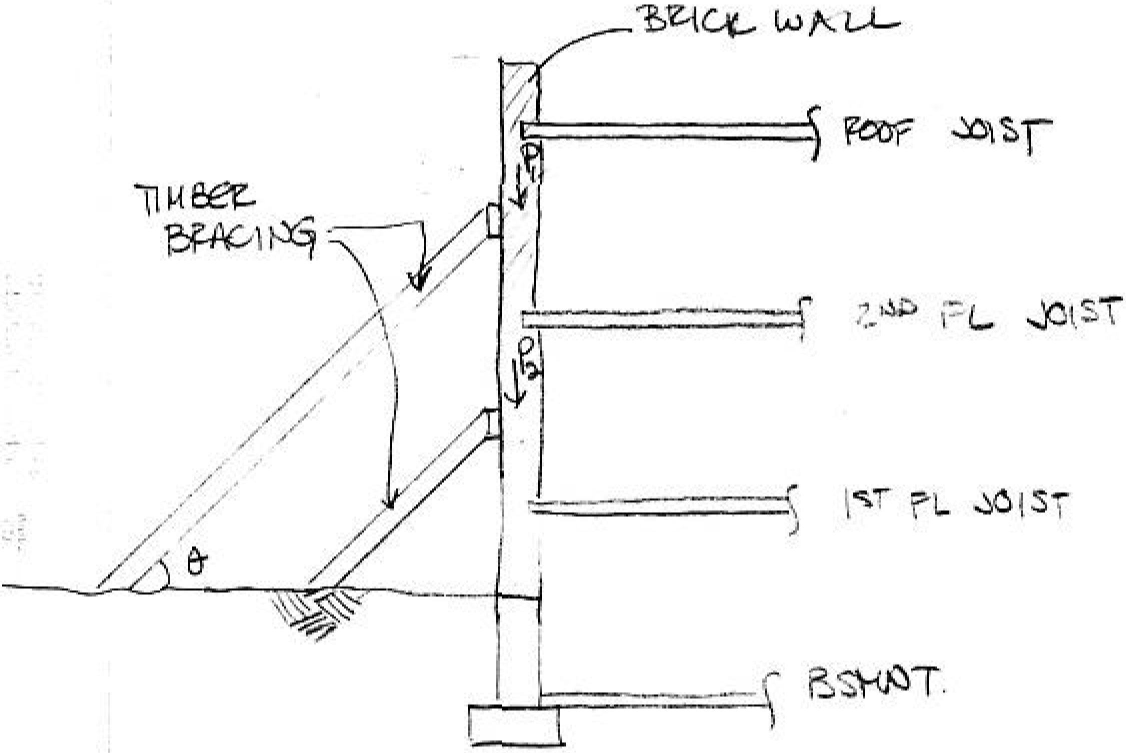
$$F_V' = 95 \text{ PSI}(.9)(2) = 171 \text{ PSI}$$

$$V' = \frac{2}{3}(171 \text{ PSI})(8'')(8'') = 7.3^k$$

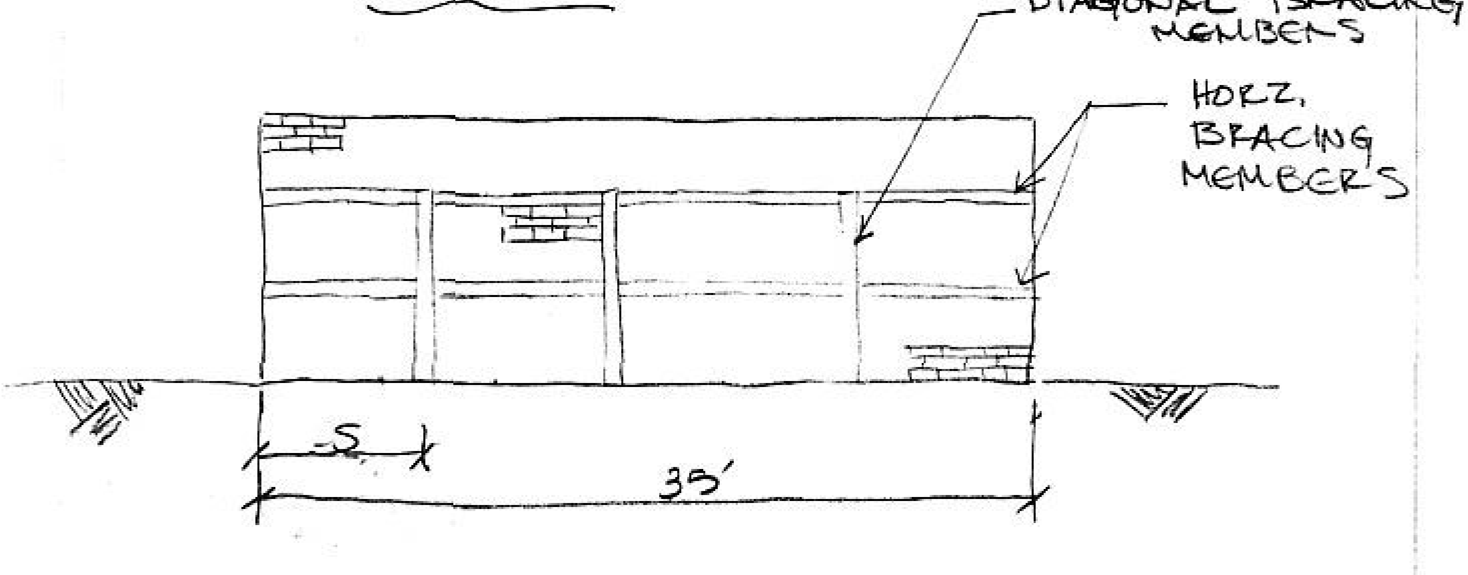
$$V_{req'd} = \text{REACTION} = \frac{wL}{2} \text{ (CONSERVATIVE)}$$

$$= \frac{14.5(35)}{2} = 0.25^k < 7.3^k \therefore \underline{\text{O.K.}}$$

RETROFIT : DIAGONAL TIMBER BRACING    OK CONSULTANTS



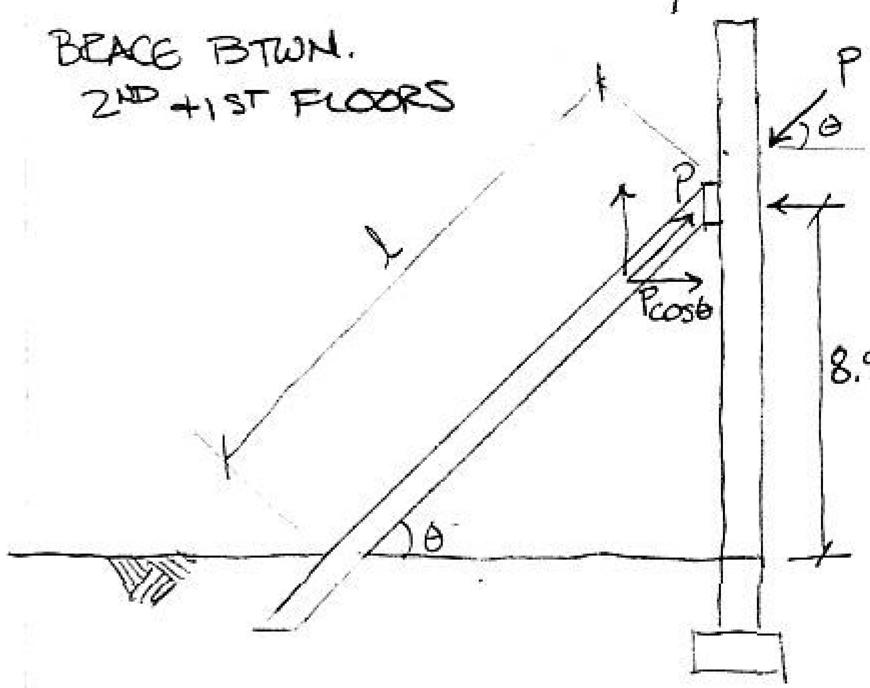

SECTION




S = BRACE SPACING

SIDE VIEW

BRACE BTWN. 2ND + 1ST FLOORS




DIAGONAL BRACE SUBJECTED TO AXIAL COMPRESSION

$9\% F_2 = 40.77$ lb/ft

TRY $S = 17'\text{-}6''$ + $\theta = 45°$

$40.77$ lb/ft $(17.5') = 713$ lb

$P\cos\theta = 713$ lb  ∴  $\underline{\underline{P = 1009}}$ lb

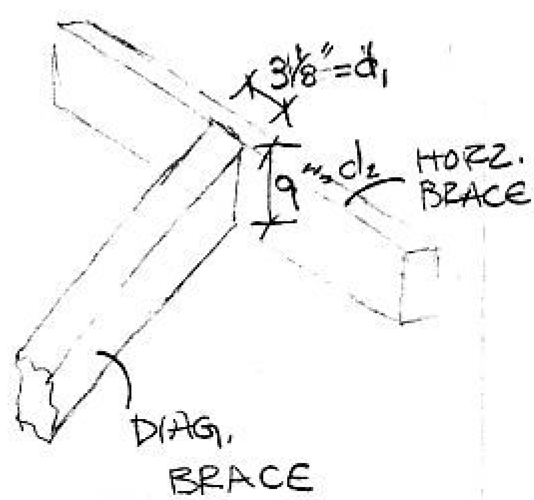
ALLOWABLE COMPRESSION CAPACITY ∥ TO GRAIN

$P' = F_c' A$

$F_c' = F_c\, C_D\, \checkmark C_M\, \checkmark C_t\, \checkmark C_F\, \checkmark C_i\, C_p$

$F_{c\parallel} = 1900$ PSI

$C_D = 0.9$



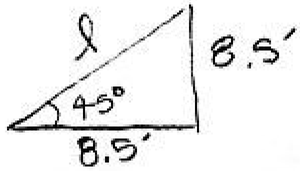

STABILITY FACTOR, $C_p$

TRY $3\frac{1}{8}'' \times 9''$ SECTION

$K_e = 1.0$

$l_e = K_e\, l$

$l = 12'$



$l_e = 1(12') = 12'$

$$C_p = \frac{1 + (F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1+(F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

$F_c^* = 1900\text{ PSI}(.9) = 1710\text{ PSI}$

$F_{cE} = \frac{K_{cE}E'}{(l_e/d)^2}$ ; $K_{cE} = 0.3$ (VISUALLY GRADED LUMBER)

$c = 0.8$

$= \frac{0.3(1.9 \times 10^6\text{ PSI})}{(12' \times 12/3\tfrac{1}{2})^2} = 268$ $\qquad \frac{F_{cE}}{F_c^*} = 0.157$

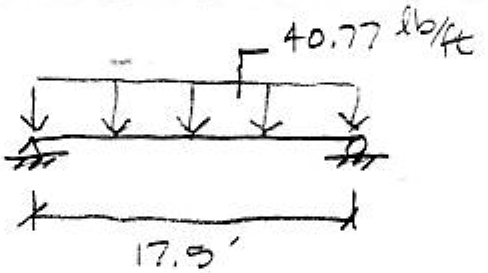
$$C_p = \frac{1+.157}{1.6} - \sqrt{\frac{1+(.157)^2}{1.6} - \frac{.157}{.8}} = 0.06$$

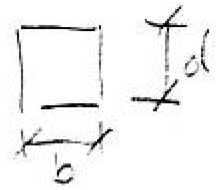
$F_c' = 1900\text{ PSI}(.9)(.06) = 102\text{ PSI}$

$P' = 102\text{ PSI}(9'')(3.125'') = 2886\text{ lb} > 1009\text{ lb}$ $\therefore$ O.K.

F.S. = 2.8

## BRACING BTWN. 2ND FL + 1ST FL




$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(40.77\,\text{lb/ft})(17.5' \times 12''/1)^4}{(.75)(384)(1.9 \times 10^6\,\text{PSI})}\left(\frac{1'}{12''}\right) = 60.4\ \text{in}^4 = \frac{bd^3}{12}$$

POSSIBLE SECTIONS

| d (") | b (") | $I_{prov}$ (in$^4$) |
|---|---|---|
| 2 | 90 | 60 |
| 2½ | 46½ | 60.5 |
| 3 | 27 | 60.7 |
| | 17 | 60.7 |
| | 1½ | 61 |
| | 8 | 60.7 |
| | 6 | 62 |
| 5½ | 4½ | 62.4 |
| 6 | 3½ | 63 |

TRY 5" × 6"

CHECK BENDING:

$$M' = F_b' S$$

$$F_b' = F_b C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$$

$C_D = 0.9$ ALL OTHER ADJ. FACTORS = 1.0

$$S = \frac{bd^2}{6} = 25\ \text{in}^3$$

$$M' = 1500\,\text{PSI}\,(.9)(25\ \text{in}^3) = 2.8^{k\cdot ft}$$

$$M_{req'd} = \frac{wL^2}{8} = \frac{(40.77)(17.5)^2}{8} = 1.56^{k\cdot ft} < 2.8^{k\cdot ft} \quad \therefore \underline{O.K.}$$

**CHECK SHEAR:**

$$V' = \frac{2F'_v bd}{3}$$

$$F'_v = F_v C_D C_m C_i C_H$$

$C_D = 0.9$ $\qquad C_M = C_i = 1.0$

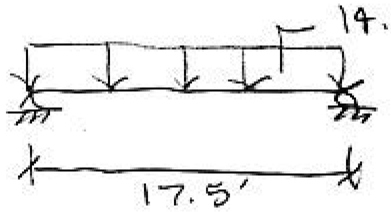
$C_H = 2.0$

$F'_v = 95(.9)(2) = 171 \text{ PSI}$

$V' = 2(171)(5)(6)/3 = 3.42^k$

$V_{max} = \frac{wL}{2} = \frac{40.77(17.5)}{2} = 0.36^k < 3.42^k \therefore \underline{\underline{O.K}}$

**BRACING BTWN. ROOF + 2ND FLOOR**




$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(14.5\text{ lb/ft})(17.5' \times 12)^4}{(.75)(384)(1.9\times10^6 \text{ PSI})}\left(\frac{1'}{12''}\right) = 21.5 \text{ in}^4 = \frac{bd^3}{12}$$

POSSIBLE SECTIONS

| d (") | b (") | $I_{prov.}$ (in⁴) |
|---|---|---|
| 2 | 32½ | 21.7 |
| 2½ | 16½ | 21.5 |
| 3 | 9½ | 21.4 |
| 3½ | 6 | 21.4 |
| 4 | 4 | 21.3 |
| 4½ | 3 | 22.8 |
| 5 | 2 | 20.8 |
| 5½ | 1½ | 21 |

TRY 4" × 4"  $S = 10.67\ in^3$ , $A = 16\ in^2$

CHECK BENDING:

$M' = F'_b S$

$F'_b = F_b C_D C_M C_t C_L C_F C_V C_{fu} C_i C_r C_c C_f$

$C_D = 0.9$

$M' = 1500\ PSI\ (.9)(10.67\ in^3)\left(\frac{1'}{12''}\right) = 1.2^{k \cdot ft}$

$M_{req'd} = \frac{wL^2}{8} = \frac{14.5\ lb/ft\ (17.5')^2}{8} = 0.56^{k \cdot ft} < 1.2^{k \cdot ft}$ ∴ O.K

CHECK SHEAR

$V' = \frac{2}{3} F'_v bd$

$F'_v = F_v C_D C_m C_t C_H$

$C_D = .9$ , $C_H = 2$ , $C_M = C_i = 1$

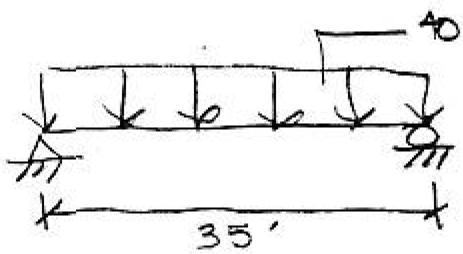
$F'_v = 171\ PSI$

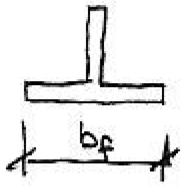
$V' = 171\ PSI\left(\frac{2}{3}\right)(16\ in^2) = 1.8^k$

$V_{req'd} = \frac{wL}{2} = \frac{14.5(17.5)}{2} = 0.13^k < 1.8^k$ ∴ O.K.

## BRACING - 2ND FLOOR → 1ST FLOOR

$3\% \; P_2 = 40.77 \text{ lb/ft}$



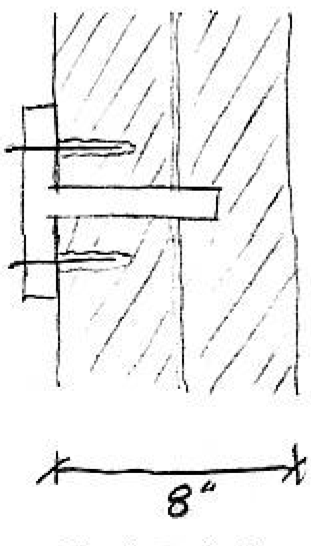




$F_y = 50 \text{ KSI}$

$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(40.77 \text{ lb/ft})(35' \times 12''/')^4}{.75(384)(29 \times 10^6 \text{ PSI})} \left(\frac{1'}{12''}\right) = 63 \text{ in}^4$$

## EMBEDMENT DEPTH (demb.)




$d_{EMB} = 2/3\,(8'') = 5.33''$

∴ USE A WT 6

TRY WT 6×85 $\quad I_x = 67.8 \text{ in}^4, \; S_x = 12.3 \text{ in}^3, \; A = 25 \text{ in}^2$

## CHECK BENDING

$$M = \frac{wL^2}{8} = \frac{40.77 \text{ lb/ft}\,(35')^2}{8} = 6.24 \text{ k·ft} \qquad f_b = \frac{M}{S}$$

$$f_b = \frac{6.24 \text{ k·ft}}{12.3 \text{ in}^3}\left(\frac{12''}{\text{ft}}\right) = 6.09 \text{ KSI}$$

$F_b = .66 F_y = .66(50^{ksi}) = 33\text{ ksi} >> 6.09\text{ ksi} \therefore \underline{\underline{O.K.}}$

CHECK SHEAR

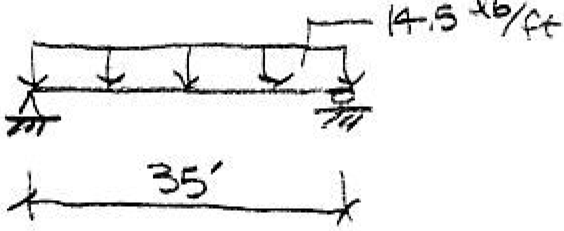
$F_v = 0.4 F_y = .4(50\text{ ksi}) = 20\text{ ksi}$

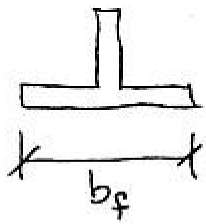
$V_{max} = \text{REACTION} = \frac{wL}{2} = \frac{40.77^{lb/ft}(35')}{2} = .713^k$
(CONSERVATIVE)

$\tau = \frac{3V}{2A} = \frac{3(.713^k)}{2(25 in^2)} = 0.04\text{ ksi} << 20^{ksi} \therefore \underline{\underline{O.K.}}$

BRACING - ROOF → 2ND FLOOR

$3\% P_1 = 14.5\ ^{lb}/_{ft}$




$\Delta = \frac{5wL^4}{384EI} = \frac{3}{4}''$

$I_{req'd} = \frac{5(14.5^{lb/ft})(35' \times 12''/1')^4}{.75''(384)(29 \times 10^6 PSI)} \left(\frac{1'}{12''}\right) = 23\text{ in}^4$

TRY WT 6×36 $I_x = 23.2\text{ in}^4,\ S_x = 4.54\text{ in}^3,\ A = 10.6\text{ in}^3$

CHECK BENDING

$M = \frac{wL^2}{8} = \frac{14.5(35')^2}{8} = 2.22^{k \cdot ft}$

$f_b = \frac{M}{S} = \frac{2.22^{k \cdot ft}}{4.54 in^3}\left(\frac{12''}{1'}\right) = 5.87\text{ ksi}$

$F_b = .66 F_y = 33\text{ ksi} > 5.87\text{ ksi} \therefore \underline{O.K.}$

CHECK SHEAR:

$F_v = .4F_y = 20^{KSI}$

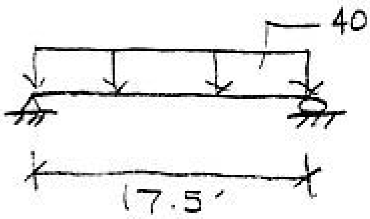
$V_{max}$ = REACTION = $\frac{wL}{2} = \frac{14.5^{lb/ft}(35')}{2} = .254^k$
(CONSERVATIVE)

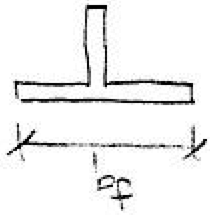
$\tau = \frac{3V}{2A} = \frac{3(.254)}{2(10.6)} = .035$ KSI << $20^{KSI}$ $\therefore$ O.K.

RETROFIT : STEEL T'S (2 SECTIONS) OK CONSULTANTS

BRACING BTWN. 2ND FLOOR + 1ST FLOOR

$3\% P_2 = 40.77 \text{ lb/ft}$




$F_y = 50^{ksi}$

$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(40.77 \text{ lb/ft})(17.5' \times 12''/')^4}{(.75'')384(29 \times 10^6 \text{ PSI})}\left(\frac{1'}{12''}\right) = 4 \text{ in}^4$$

TRY WT 5x6 $I_x = 4.35 \text{ in}^4$, $S_x = 1.22 \text{ in}^3$, $A = 1.77 \text{ in}^2$

CHECK BENDING

$$M = \frac{wL^2}{8} = \frac{40.77 \text{ lb/ft}(17.5')^2}{8} = 1.56^{k \cdot ft}$$

$$f_b = \frac{M}{S} = \frac{1.56^{k \cdot ft}}{1.22 \text{ in}^3}\left(\frac{12''}{1'}\right) = 15.3 \text{ KSI}$$

$F_b = .66 F_y = 33 \text{ KSI} > 15.3 \text{ KSI}$ $\therefore$ O.K.

CHECK SHEAR

$F_v = .4 F_y = 20^{KSI}$

$$V_{Max} = \frac{wL}{2} = \frac{40.77(17.5)}{2} = .357^k$$

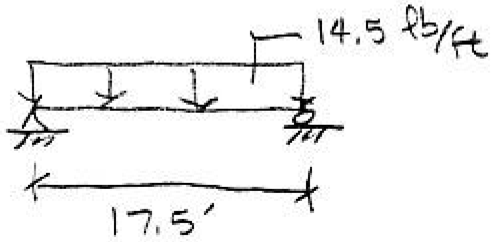
$$\tau = \frac{3V}{2A} = \frac{3(.357^k)}{2(1.77 \text{ in}^2)} = 0.3 \text{ KSI} < 20 \text{ KSI}$$ $\therefore$ O.K.

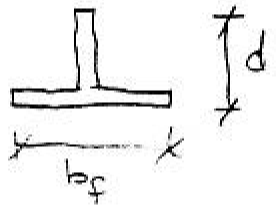
250 lb
CAP. LIFT/
CRANE

UNITED
RENTALS
CONST. EQUIP.

## BRACING BTWN ROOF + 2ND FLOOR

$3\% P_1 = 14.5 \text{ lb/ft}$




$$\Delta = \frac{5wL^4}{384EI} = 3/4''$$

$$I_{req'd} = \frac{5(14.5 \text{ lb/ft})(17.5' \times 12''/\text{ft})^4}{(.75)(384)(29 \times 10^6 \text{ PSI})}\left(\frac{1'}{12''}\right) = 2 \text{ in}^4$$

TRY WT 4x5 $\quad I_x = 2.15 \text{ in}^4$, $S_x = 0.717 \text{ in}^3$, $A = 1.48 \text{ in}^2$

CHECK BENDING

$$M = \frac{wL^2}{8} = \frac{14.5(17.5)^2}{8} = 0.56 \text{ k.ft}$$

$$f_b = \frac{M}{S} = \frac{0.56 \text{ k.ft}}{0.717 \text{ in}^3}\left(\frac{12''}{1'}\right) = 9.37 \text{ KSI}$$

$$F_b = .66 F_y = 33 \text{ KSI} > 9.37 \text{ KSI} \therefore \underline{\text{O.K.}}$$

CHECK SHEAR

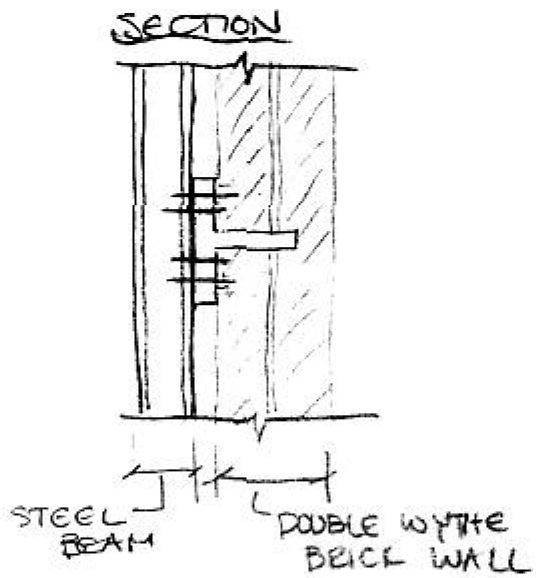
$$F_v = .4 F_y = 20 \text{ KSI}$$

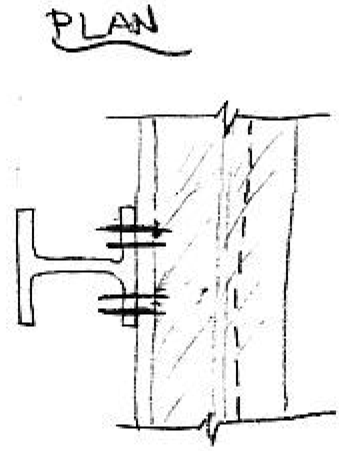
$$V_{MAX} = \frac{wL}{2} = \frac{14.5(17.5)}{2} = 0.13^k$$

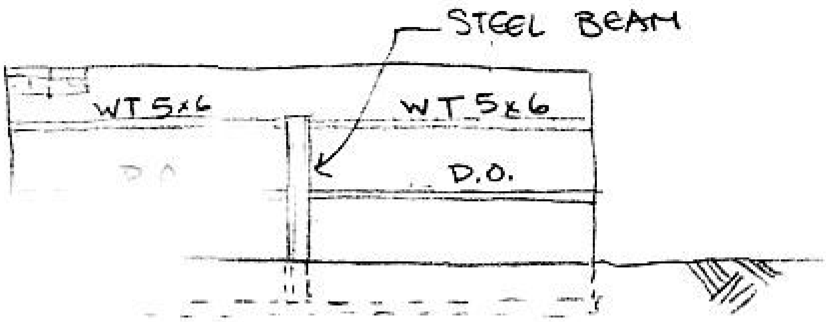
$$\tau = \frac{3V}{2A} = \frac{3(.13^k)}{2(1.48 \text{ in}^2)} = 0.13 \text{ KSI} < 20 \text{ KSI} \therefore \underline{\text{O.K.}}$$

RETROFIT: STEEL T's (2 SECTIONS)   OK CONSULTANTS

VERTICAL SUPPORT FOR T's

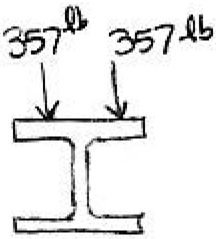


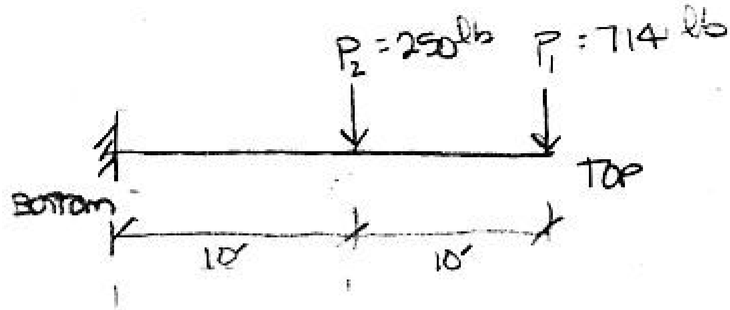



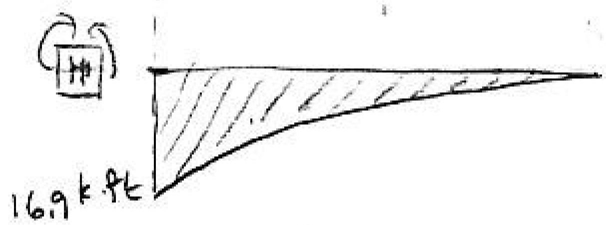

SIDE VIEW

REACTION @ BEAM FROM HORZ. TEE'S = 357 lb

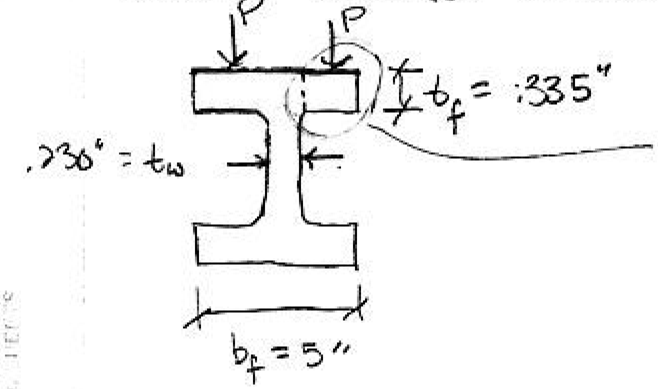


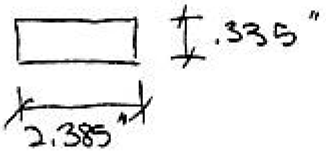




TRY W14x22



CHECK LOCAL BUCKLING OF FLANGE




$$\frac{b}{t} = \frac{2.385}{.335} = 7.12$$

$$\frac{95}{\sqrt{F_y}} = \frac{95}{\sqrt{50}} = 13.4 \qquad \frac{b}{t} < \frac{95}{\sqrt{F_y}}$$

$$\frac{b}{t} < \frac{65}{\sqrt{F_y}} = 9.19 \quad \therefore \text{ NO BUCKLING OF FLANGE}$$

ANCHOR BOLTS IN FLANGES

ALLOW. TENSILE LOAD:

$$B_a = 0.5\,A_p\sqrt{f'_m} \quad ; \quad A_p = \pi l_b^2 = \pi(3")^2 = 28.3\,in^2$$

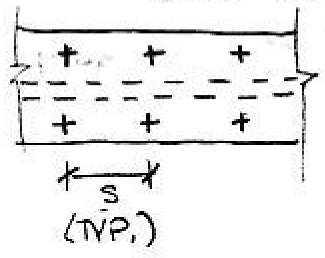
$$= .5(28.3)\sqrt{250}$$

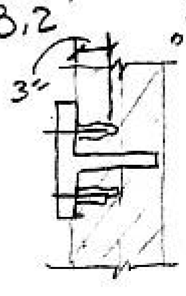
$$= 224\ lb$$

$$\phi B_a = 0.6\,(224) = 134\ lb$$

MAX. SPACING (BTWN 1ST + 2ND FL)

$$s = \frac{134\ lb}{40.77\ lb/ft} = 3.2' \quad \therefore \text{ USE } 3'$$




MAX. SPACING (BTWN. ROOF + 2ND FL)

$$s = \frac{134\ lb}{14.5\ lb/ft} = 9.2' \quad \therefore \text{ USE } 5\tfrac{1}{2}'$$

TOTAL # BOLTS

| | |
|---|---|
| 1st → 2ND FL | 22 |
| ROOF → 2ND FL | 12 |

EMBEDMENT DEPTH = 3"

Schoor DePalma
8 Penn Center, 1628 JFK Boulevard,
Philadelphia, PA 19103-2113
Phone: 215-972-8100
Fax: 215-972-8181

Title :
Dsgnr:
Description :

Scope :

Job #
Date: 3:49AM, 13 MAY 01

Rev: 510300
User: KW-0603859, Ver 5.1.3, 22-Jun-1999, Win32
(c) 1983-99 ENERCALC

# Steel Beam Design

Page 1
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## Description

## General Information

Calculations are designed to AISC 9th Edition ASD and 1997 UBC Requirements

**Steel Section : W14X22**

| | | | | |
|---|---|---|---|---|
| Center Span | 20.00 ft | Fixed-Free | Fy | 50.00ksi |
| Left Cant. | 0.00 ft | | Load Duration Factor | 1.00 |
| Right Cant | 0.00 ft | LL & ST Don't Act Together | Elastic Modulus | 29,000.0ksi |
| Lu : Unbraced Length | 10.00 ft | | | |

## Point Loads

| | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | |
|---|---|---|---|---|---|---|---|---|
| Dead Load | 0.720 | 0.250 | | | | | | k |
| Live Load | | | | | | | | k |
| Short Term | | | | | | | | k |
| Location | 20.000 | 10.000 | | | | | | ft |

## *Summary*

**Beam OK**
**Static Load Case Governs Stress**

Using: W14X22 section, Span = 20.00ft, Fy = 50.0ksi
End Fixity = Fixed-Free, Lu = 10.00ft, LDF = 1.000

| | Actual | Allowable |
|---|---|---|
| Moment | 16.900 k-ft | 44.112 k-ft |
| fb : Bending Stress | 7.001 ksi | 18.275 ksi |
| **fb / Fb** | **0.383 : 1** | |
| Shear | 0.970 k | 63.204 k |
| fv : Shear Stress | 0.307 ksi | 20.000 ksi |
| **fv / Fv** | **0.015 : 1** | |

| | |
|---|---|
| Max. Deflection | -0.637 in |
| Length/DL Defl | 753.2 : 1 |
| Length/(DL+LL Defl) | 753.2 : 1 |

## Force & Stress Summary

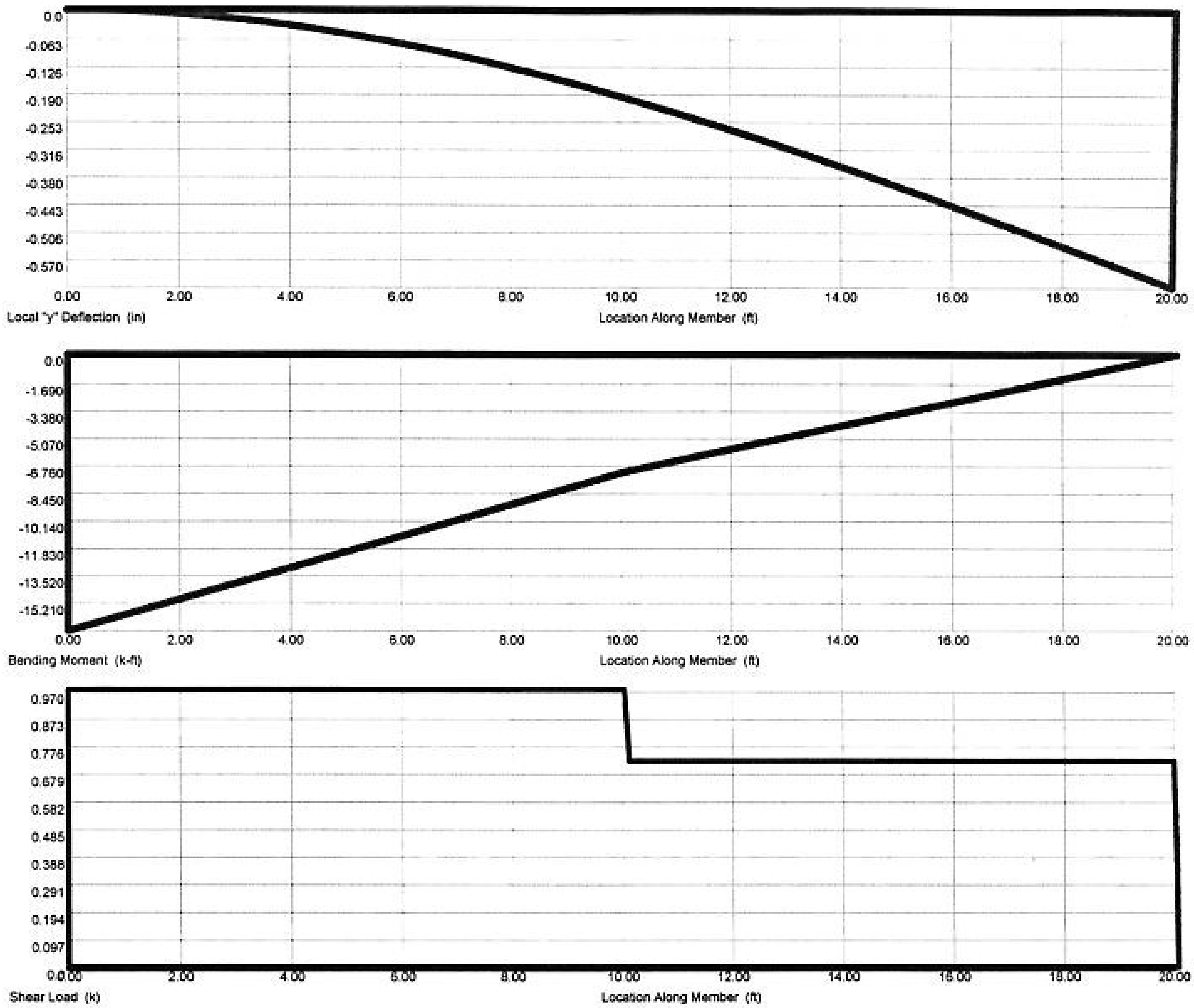
<<-- These columns are Dead + Live Load placed as noted -->>

| | Maximum | DL Only | LL @ Center | LL+ST @ Center | LL @ Cants | LL+ST @ Cants | |
|---|---|---|---|---|---|---|---|
| Max. M + | 16.90 k-ft | | | | | | k-ft |
| Max. M - | | -16.90 | | | | | k-ft |
| Max. M @ Left | | | | | | | k-ft |
| Max. M @ Right | | | | | | | k-ft |
| Shear @ Left | 0.97 k | 0.97 | | | | | k |
| Shear @ Right | 0.72 k | 0.72 | | | | | k |
| Center Defl. | -0.637 in | -0.637 | 0.000 | -0.637 | 0.000 | 0.000 | in |
| Left Cant Defl | 0.000 in | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | in |
| Right Cant Defl | 0.000 in | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | in |
| ...Query Defl @ | 0.000 ft | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | in |
| Reaction @ Left | 0.97 | 0.97 | | 0.97 | | | k |
| Reaction @ Rt | | | | | | | k |

**Fa calc'd per 1.5-2, K*L/r > Cc**

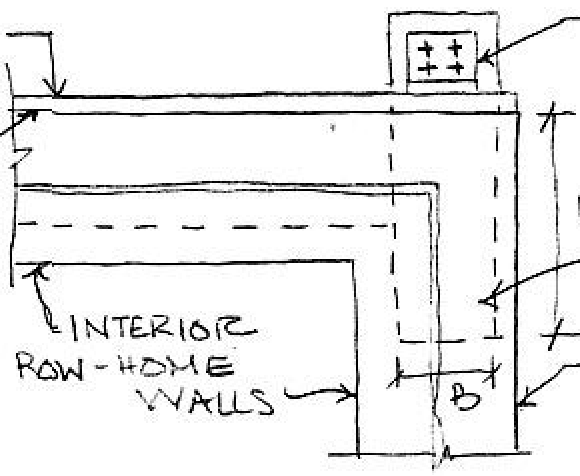
## Section Properties W14X22

| | | | | | |
|---|---|---|---|---|---|
| Depth | 13.740 in | Weight | 22.04 #/ft | r-xx | 5.537 in |
| Width | 5.000in | I-xx | 199.00 in4 | r-yy | 1.039 in |
| Web Thick | 0.230 in | I-yy | 7.00 in4 | Rt | 1.250 in |
| Flange Thickness | 0.335 in | S-xx | 28.967 in3 | | |
| Area | 6.49 in2 | S-yy | 2.800 in3 | | |



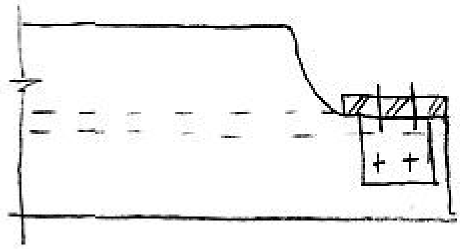
0.0
-0.063
-0.126
-0.190
-0.253
-0.316
-0.380
-0.443
-0.506
-0.570
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
Local "y" Deflection (in)
Location Along Member (ft)
0.0
-1.690
-3.380
-5.070
-6.760
-8.450
-10.140
-11.830
-13.520
-15.210
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
Bending Moment (k-ft)
Location Along Member (ft)
0.970
0.873
0.776
0.679
0.582
0.485
0.388
0.291
0.194
0.097
0.0
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
Shear Load (k)
Location Along Member (ft)

CONNECTIONS INTO EXTERIOR WALL




N = REQ'D EMBEDMENT DEPTH

COPE BOTTOM FLANGE @ PLATE INTERSECTION



AREA OF PLATE REQ'D

REACTION FROM TEE $= 357^{lb} = 0.5 A_p \sqrt{f'_m}$

$$A_p = \frac{357(2)}{\sqrt{250}} = 45 \text{ in}^2$$

$B = 6"$, $N = 8"$ $\qquad A_{prov} = 48 \text{ in}^2$

BENDING STRESS OF PLATE

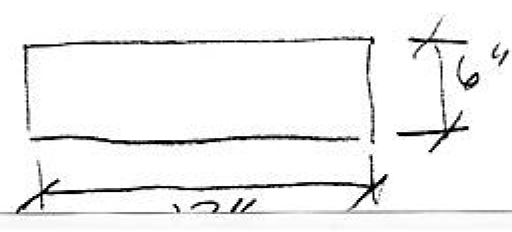
$$f_p = \frac{357 \text{ lb}}{48 \text{ in}^2} = 7.5 \text{ PSI}$$

$F_b = 0.75 F_y = 27$ KSI

THICKNESS

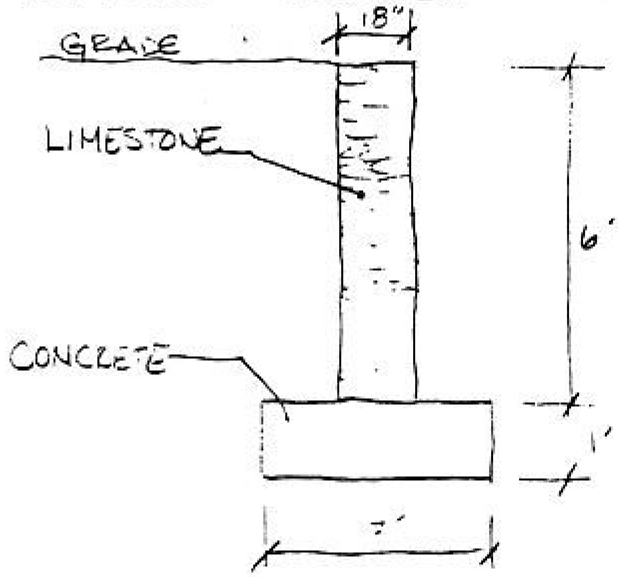
$$t = \sqrt{\frac{3 f_p n^2}{F_b}} = \sqrt{\frac{3(7.5)(3)^2}{27{,}000}} = .08"$$

USE $t = 1/2"$



Appendix F: Foundation Wall Source: Lippincott Engineering Associates, New Jersey

1. FOUNDATION ANALYSIS – STRIP FOOTING

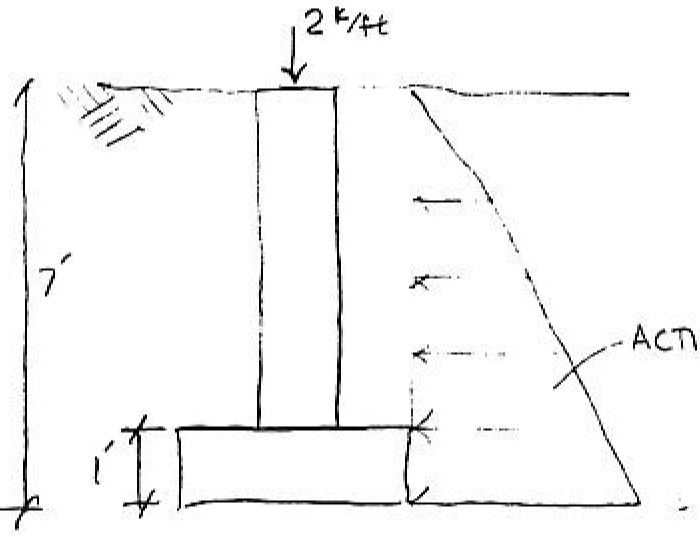



NOTE: ORIGINAL MORTAR PROBABLY TYPE O, BUT SO DETERIORATED THAT ITS CONSISTENCY IS SIMILAR TO SAND.

LIMESTONE PROPERTIES
MIN. COMP. STRENGTH = 1800 PSI
MIN. MODULUS OF RUPTURE = 400 PSI
MIN. DENSITY = 110 PCF

} Drysdale, Hamid, + Baker: "Masonry Structures"

LOAD / FT. OF WALL = ROOF + FLOOR LOADS + WT. OF MASONRY WALL
$= [(13.5 + 20)\text{PSF}(15') + (15 + 40)\text{PSF}(15') + (15 + 30)\text{PSF}(15')$
$+ 2000\ \text{lb/ft}] / 2$
$= 2\ ^{k}/\text{ft}$

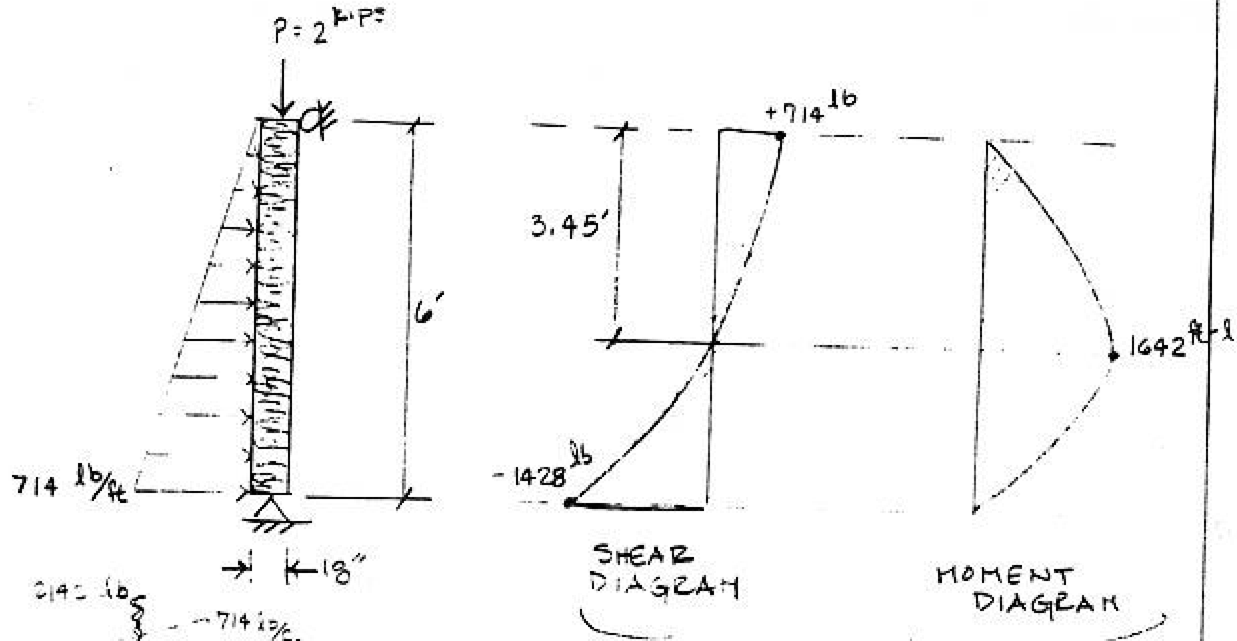



ASSUME $\phi = 15°$
$\gamma_{SAT} = 70\ \text{lb/ft}^3$
$K_a = \tan^2(45 + \frac{\phi}{2})$
$= 1.7$

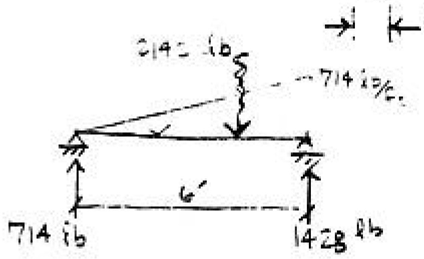
Active Pressure from fill on wall (NOT FOOTING)

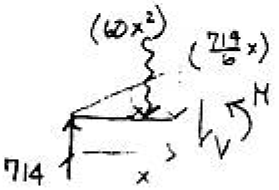
$P_A = K_a \gamma H = 1.7(70\ \text{lb/ft}^3)(6') = 714\ \text{PSF}$

ANALYZING 1' STRIP OF WALL $\therefore$ $P_A = 714\ ^{lb}/\text{ft}$




DUE TO LATERAL EARTH PRESSURE




$\uparrow \Sigma F_y = 0 = 714^{lb} - 60x^2 - V \Rightarrow V = 714^{lb} - 60x^2$

$M_{max}$ @ $V = 0 \Rightarrow x = 3.45'$

$\circlearrowleft \Sigma M = 0 = M + 60x^2\left(\frac{x}{3}\right) - 714x \Rightarrow M = 714x - 20x^3$

$M_{max} = M(3.45') = 1642^{ft \cdot lb}$

CHECK STRESSES @ MAX. MOMENT (3.45' FROM TOP)

WT. OF WALL

$W = 110 \text{ PCF} (18")\left(\frac{1'}{12"}\right)(1') = 165 \text{ lb/ft}$

ASSUME ≃ 10% VOIDS BTWN. STONES ∴ $W = 149 \text{ lb/ft}$

WALL PROPERTIES

$A = 18"(12") = 216 \text{ in}^2$

$I = \frac{bt^3}{12} = \frac{12"(18")^3}{12} = 5832 \text{ in}^4$

$S = \frac{bt^2}{6} = \frac{12"(18")^2}{6} = 648 \text{ in}^3$

REDUCE BY 10% FOR VOIDS

$A = 195 \text{ in}^2$

$I = 5250 \text{ in}^4$

$S = 580 \text{ in}^3$

LOAD @ 3.45' FROM TOP (MAX. MOMENT LOCATION)

$P = 149\ \text{lb/ft}(3.45') + 2000\ \text{lb} = 2514\ \text{lb}$

MOMENT @ 3.45' FROM TOP

$M = 1642\ \text{ft}\cdot\text{lb}$

CHECK FLEXURAL TENSION STRESS:

$f_t = -\frac{P}{A} + \frac{M}{S} = -\frac{2514\ \text{lb}}{195\ \text{in}^2} + \frac{1642\ \text{ft}\cdot\text{lb}}{580\ \text{in}^3}\left(\frac{12''}{\text{ft}}\right) \Rightarrow \underline{21.1\ \text{PSI} = f_t}$

* NOTE: WITHOUT MORTAR BONDING, THE FOUNDATION WALL CANNOT ADEQUATELY TRANSFER THE 21 PSI TENSILE STRESSES.

CHECK FOR COMPRESSION STRESSES:

$r = \sqrt{I/A} = \sqrt{5230/195} \Rightarrow 5.19 = r =$ RADIUS OF GYRATION

$\frac{kh}{r} = \frac{(1)(6')(12''/\text{ft})}{5.19} = 13.87$

$F_a = \frac{f'_M}{4}\left[1 - \left(\frac{kh}{140r}\right)^2\right]$

* MIN COMP. STRENGTH OF LIMESTONE IS 1800 PSI BUT WALL COMP. STRENGTH IS MUCH LOWER DUE TO NO MORTAR ∴ ASSUME WORST-CASE $f'_M \simeq \frac{1}{2}(1800) = 900\ \text{PSI}$

$F_a = \frac{900\ \text{PSI}}{4}\left[1 - \left(\frac{13.87}{140}\right)^2\right] = 223\ \text{PSI}$

$F_b = \frac{f'_m}{3} = \frac{900\ \text{PSI}}{3} = 300\ \text{PSI}$

UNITY EQN: $\frac{f_a}{F_a} + \frac{f_b}{F_b} = \frac{P/A}{F_a} + \frac{M/S}{F_b} \leq 1$

$f_a = P/A = \frac{2514\ \text{lb}}{195\ \text{in}^2} = 12.9\ \text{PSI}$

$f_b = M/S = \frac{1642\ \text{ft}\cdot\text{lb}}{580\ \text{in}^3}\left(\frac{12''}{\text{ft}}\right) = 34\ \text{PSI}$

$\frac{12.9\ \text{PSI}}{223\ \text{PSI}} + \frac{34\ \text{PSI}}{300\ \text{PSI}} = \underline{\underline{0.171 < 1}}\ \ \underline{\underline{\therefore\ \text{O.K.}}}$

APPENDIX C

## SAFETY AGAINST BUCKLING

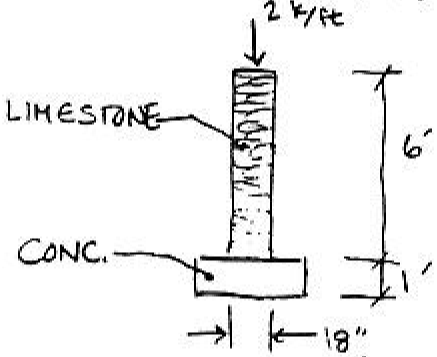
$$P_e = \frac{\pi^2 E_M I}{h^2}\left(1 - 0.577\frac{e}{r}\right)^3$$

$$E_M \approx 800(f'_M) = 800(900) = 720{,}000 \text{ PSI}$$

$$P_e = \frac{\pi^2(720{,}000 \text{ PSI})(5250 \text{ in}^4)}{(6' \times 12''/ft)^2}\left(1 - .577\frac{\cancel{1.0}\ 0}{\cancel{3.19}}\right)^3 = 7197^{kips}$$

$$\tfrac{1}{4}P_e = 1800^{kips} \gg P = 2.31^{kips} \quad \therefore \text{ O.K.}$$

ANALYSIS OF FOUNDATION WALL PREVIOUS TO FILLING IN DEMOLISHED UNIT'S BASEMENT (NO LATERAL EARTH PRESSURE)




WALL PROPERTIES: (SEE FIRST ANALYSIS)

WT. OF WALL = 165 lb/ft

ASSUME ≃ 10% VOIDS BTWN. STONES

∴ W = 149 lb/ft

$A = 195\ in^2$ , $I = 5250\ in^4$

$P$ @ Mid-Ht = 149 lb/ft (3') + 2000 lb/ft (1') = 2447 lb

CHECK FLEXURAL TENSILE STRESS:

$f_t = -\frac{P}{A} = -\frac{2447\ lb}{195\ in^2} = -12.5$ PSI ∴ COMPLETELY IN COMPRESSION

CHECK COMPRESSION STRESSES:

$r = 5.19"$ , $\frac{kh}{r} = 13.87$ (SEE FIRST ANALYSIS)

$F_a = \frac{f'_m}{4}\left[1 - \left(\frac{kh}{140r}\right)^2\right]$ $f'_m = 900$ PSI

$= \frac{900\ PSI}{4}\left[1 - \left(\frac{13.87}{140}\right)^2\right] = 223$ PSI

$F_b = 1/3 f'_m = 300$ PSI

UNITY EQN: $\frac{f_a}{F_a} + \frac{\cancel{f_b}^{\,0}}{F_b} \leq 1 \Rightarrow \frac{12.5\ PSI}{223\ PSI} = 0.056 << 1$

SAFETY AGAINST BUCKLING:

$P_e = \frac{\pi^2 E_m I}{h^2}\left(1 - 0.577\cancel{\frac{e}{r}}^{\,0}\right)^3 = 7197^k$ (SEE 1ST ANALYSIS)

$1/4\ P_e = 1800$ KIPS $>> P = 2.447^k$ ∴ OK

NOTE:

* FOUNDATION WALL STRUCTURALLY STABLE PREVIOUS TO INTRODUCTION OF LATERAL EARTH PRESSURES.

| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 0 | 1.00 | 480 | 4.2 |
| 70 | 0 | 1.00 | 420 | 0.0 |
| 60 | 0 | 1.00 | 360 | -4.3 |
| 50 | 0 | 1.00 | 300 | -8.5 |
| 40 | 0 | 1.00 | 240 | -12.8 |
| 30 | 0 | 1.00 | 180 | -17.1 |
| 20 | 0 | 1.00 | 120 | -21.3 |
| 10 | 0 | 1.00 | 60 | -25.6 |

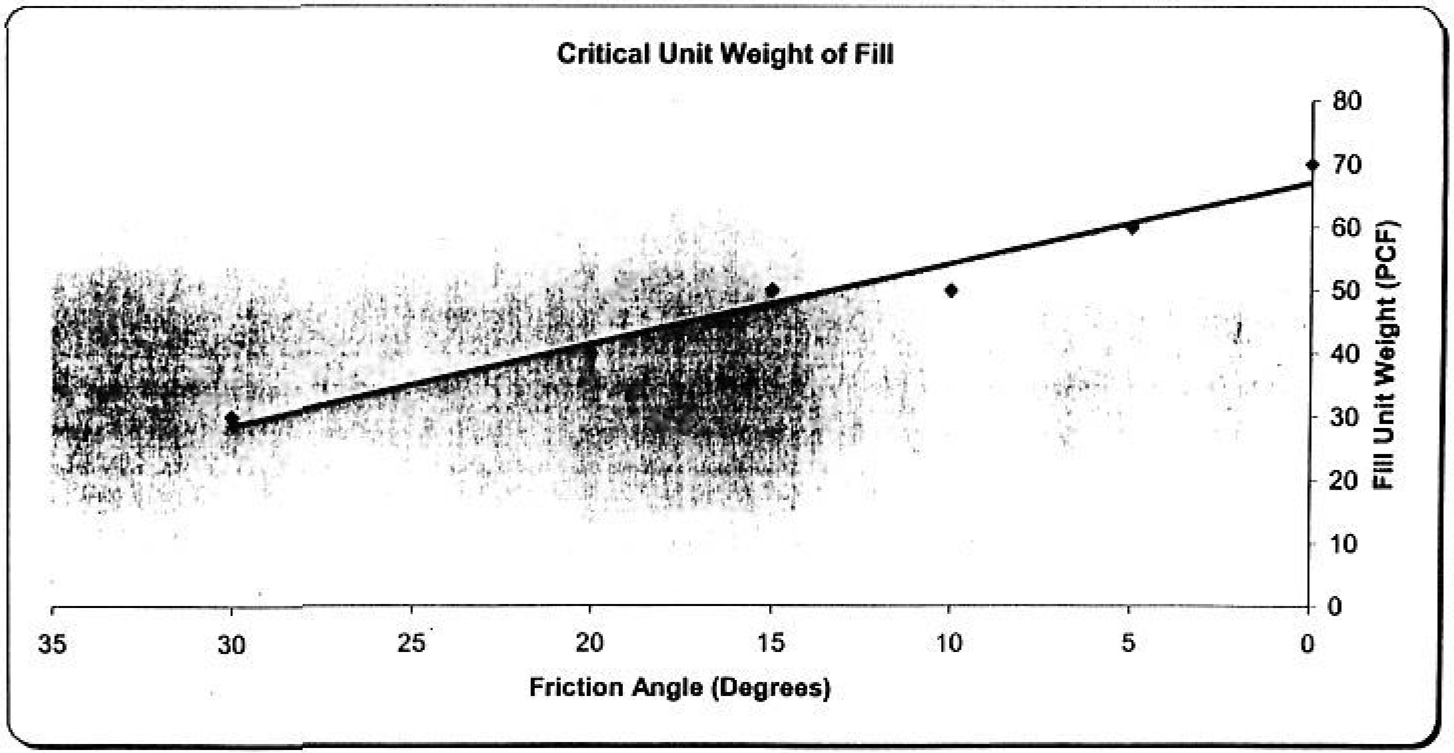
| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 15 | 1.70 | 815 | 28.0 |
| 70 | 15 | 1.70 | 713 | 20.8 |
| 60 | 15 | 1.70 | 611 | 13.6 |
| 50 | 15 | 1.70 | 510 | 6.3 |
| 40 | 15 | 1.70 | 408 | -0.9 |
| 30 | 15 | 1.70 | 306 | -8.1 |
| 20 | 15 | 1.70 | 204 | -15.4 |
| 10 | 15 | 1.70 | 102 | -22.6 |

| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 5 | 1.19 | 572 | 10.7 |
| 70 | 5 | 1.19 | 500 | 5.7 |
| 60 | 5 | 1.19 | 429 | 0.6 |
| 50 | 5 | 1.19 | 357 | -4.5 |
| 40 | 5 | 1.19 | 286 | -9.6 |
| 30 | 5 | 1.19 | 214 | -14.6 |
| 20 | 5 | 1.19 | 143 | -19.7 |
| 10 | 5 | 1.19 | 71 | -24.8 |

| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 20 | 2.04 | 979 | 39.7 |
| 70 | 20 | 2.04 | 857 | 31.0 |
| 60 | 20 | 2.04 | 734 | 22.3 |
| 50 | 20 | 2.04 | 612 | 13.6 |
| 40 | 20 | 2.04 | 490 | 4.9 |
| 30 | 20 | 2.04 | 367 | -3.8 |
| 20 | 20 | 2.04 | 245 | -12.5 |
| 10 | 20 | 2.04 | 122 | -21.2 |

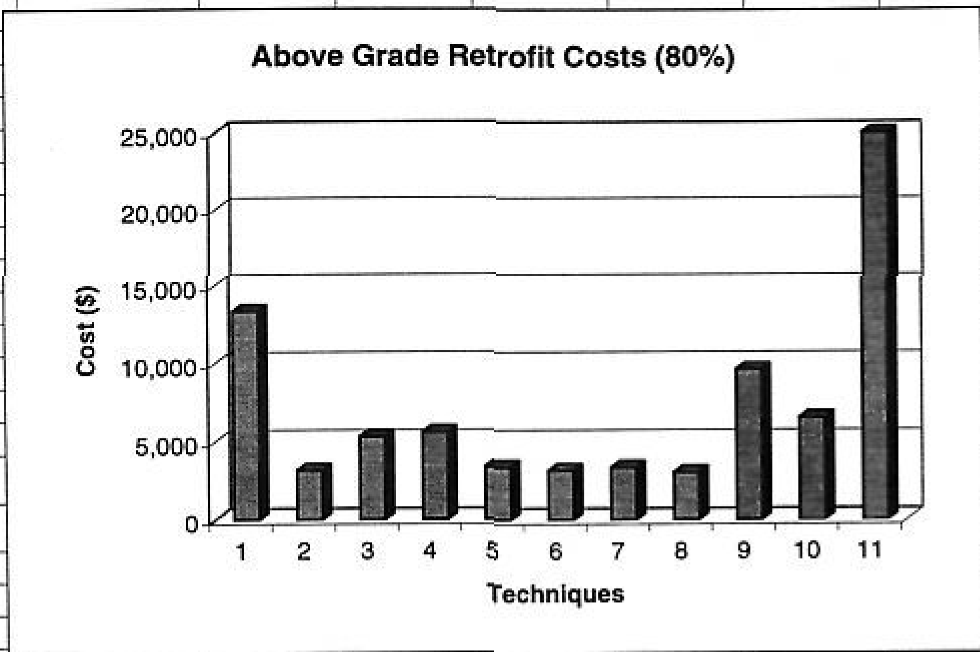
| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 10 | 1.42 | 682 | 18.5 |
| 70 | 10 | 1.42 | 597 | 12.5 |
| 60 | 10 | 1.42 | 511 | 6.5 |
| **50** | **10** | **1.42** | **426** | **0.4** |
| 40 | 10 | 1.42 | 341 | -5.6 |
| 30 | 10 | 1.42 | 256 | -11.7 |
| 20 | 10 | 1.42 | 170 | -17.7 |
| 10 | 10 | 1.42 | 85 | -23.8 |

| Saturated Unit Weight (PCF) | Friction Angle (Degrees) | Active Earth Pressure Coefficient, Ka | Earth Pressure at Base, $P_A$ (lb/ft) | Flexural Tensile Stresses in Wall, $f_t$ (psi) |
|---|---|---|---|---|
| 80 | 30 | 3.00 | 1440 | 72.4 |
| 70 | 30 | 3.00 | 1260 | 59.6 |
| 60 | 30 | 3.00 | 1080 | 46.8 |
| 50 | 30 | 3.00 | 900 | 34.0 |
| 40 | 30 | 3.00 | 720 | 21.3 |
| **30** | **30** | **3.00** | **540** | **8.5** |
| 20 | 30 | 3.00 | 360 | -4.3 |
| 10 | 30 | 3.00 | 180 | -17.1 |



## ANAYSIS BASED ON A 2 STORY ROW HOME - NORTH PHILADELPHIA

MAJOR/ ALTERNATIVE RETROFITTING TECHNIQUES - ABOVE GRADE

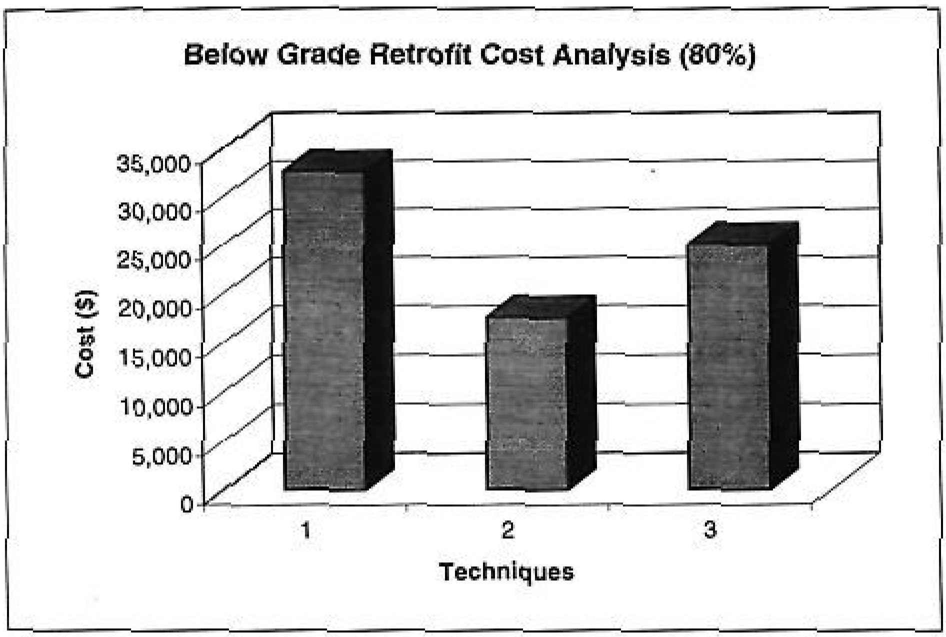



**Key:**

| | | | |
|---|---|---|---|
| 1 | Attachment of an Additional Wythe | 6 | Pressure Treated Timber Bracing |
| 2 | Anchoring & Tying of Joists to Wall | 7 | Plastic Timber |
| 3 | Shotcrete | 8 | Treated Lumber |
| 4 | Ferrocement | 9 | Applying Reinforced Composite Fabrics (RCFs) |
| 5 | Steel Bracing | 10 | Demolition |
| | | 11 | Real-Estate Worth |

## ANAYSIS BASED ON A 2 STORY ROW HOME - NORTH PHILADELPHIA

MAJOR/ ALTERNATIVE RETROFITTING TECHNIQUES - BELOW GRADE




**Key:**

1 Constructing a New Foundation Wall
2 Option 1: Grout Injection
3 Option 2: Capping with Concrete

| ANAYSIS BASED ON A 2 STORY ROW HOME - NORTH PHILADELPHIA | | | |
|---|---|---|---|
| MAJOR/ ALTERNATIVE RETROFITTING TECHNIQUES - ABOVE GRADE | | | |
| *Technique* | *Cost ($)* | | |
| ATTACHMENT OF ADDITIONAL WYTHE | 13,366.25 | | |
| ANCHORING & TYING JOISTS | 3,175.13 | | |
| SHOTCRETE/ SPRAYED MORTAR/ GUNITE/ JETCRETE | 5,311.25 | | |
| *FERROCEMENT* | *5,582.50* | | |
| EXTERNAL BRACING | | | |
| Option 1: Steel bracing | 3,390.48 | | |
| Option 2: Pressure Treated Timber | 3,173.48 | | |
| *Option 3: Plastic Timber* | *3,356.58* | | |
| Option 4: Treated Lumber | 3,051.43 | | |
| APPLYING REINFORCED COMPOSITE FABRICS (RCFs) | 9,588.56 | | |
| DEMOLITION | 6,500.00 | | |
| *REAL-ESTATE WORTH* | *25,000.00* | | |
| MAJOR/ ALTERNATIVE RETROFITTING TECHNIQUES - BELOW GRADE | | | |
| CONSTRUCTING NEW FOUNDATION WALL | 32,686.23 | | |
| RESTORING CURRENT FOUNDATION WALL | | | |
| Option 1: Grout Injection | 17,542.78 | | |
| *Option 2: Capping with Concrete* | *25,062.53* | | |

| Description | Unit | Quantity | Material ($) | | Labor ($) | | Equipment ($) | | Total ($) | Net Cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Unit | Total | Unit | Total | Unit | Total | | |
| **MOBILIZATION OF SITE** | | | | | | | | | | |
| **EXCAVATION & FILL** | | | | | | | | | | |
| Dozer b/filling bulk up to 300', haul, no compaction | CY | 190.00 | | 0.00 | 0.28 | 53.20 | 0.61 | 115.90 | 169.10 | |
| | | | | | | | | | | 169.10 |
| **MAJOR RETROFITTING TECHNIQUES** | | | | | | | | | | |
| **FLASHING PARAPET WALL** , flashing assumed @ 100% | | | | | | | | | | |
| Brick, 4" brick, 4" backup block | LF | 35.00 | 19.50 | 682.50 | 30.00 | 1,050.00 | | | 1,732.50 | |
| | | | | | | | | | | 1,732.50 |
| **MOISTURE PROTECTION** | | | | | | | | | | |
| **Option 1: Water Repellents** | | | | | | | | | | |
| Water vased liquid, roller applied | SF | 875.00 | 0.55 | 481.25 | 0.06 | 52.50 | | | 533.75 | |
| | | | | | | | | | | 533.75 |
| **DOUBLE WT STEEL SECTIONS BRACING** | | | | | | | | | | |
| Saw cutting, brick or masonry w/hand held saw, per inch of depth | LF | 70.00 | 1.25 | 87.50 | 7.30 | 511.00 | 2.60 | 182.00 | 780.50 | |
| WT 5X6 | LF | 35.00 | 5.60 | 196.00 | 2.98 | 104.30 | 2.15 | 75.25 | 375.55 | |
| W14X22 | LF | 31.00 | 13.25 | 410.75 | 1.80 | 55.80 | 1.30 | 40.30 | 506.85 | |
| 1" diameter bolts, 3" long | Ea | 30.00 | 1.31 | 39.30 | | 0.00 | | 0.00 | 39.30 | |
| | | | | | | | | | | 921.70 |
| **ANCHORING & TYING JOISTS** | | | | | | | | | | |
| **Option 1: composite/multiwythe solid wall** | | | | | | | | | | |
| Bolt anchors for brick 1/2" diam., 2 1/2" long, double | Ea | 200.00 | 1.85 | 370.00 | 1.85 | 370.00 | | | 740.00 | |
| Angle framing, field fabricated, 4" and larger | Lb | 700.00 | 0.35 | 245.00 | 1.77 | 1,239.00 | 0.19 | 133.00 | 1,617.00 | |
| | | | | | | | | | | 2,357.00 |
| **COST BENEFIT OF DEMOLITION AND RECONSTRUCTION** | | | | | | | | | | |
| **DEMOLITION** As per TPI Metro (September 29, 2000) | | | | | | | | | | |
| **Option 1:Two (2) Story Row Home** | Ea | 1.00 | | | | | | | 6,500.00 | |
| | | | | | | | | | | 6,500.00 |
| **Option 2:Three (3) Story Row home** | Ea | 1.00 | | | | | | | 11,000.00 | |
| | | | | | | | | | | 11,000.00 |
| **REAL-ESTATE WORTH** Realtor: ERA America Realty, Philadelphia, PA | | | | | | | | | | |
| **Option 1:Two (2) Story Row Home** | Ea | 1.00 | | | | | | | 25,000.00 | |
| | | | | | | | | | | 25,000.00 |
| **Option 2:Three (3) Story Row home** | Ea | 1.00 | | | | | | | 35,000.00 | |
| | | | | | | | | | | 35,000.00 |
| **TOTAL ABOVE AND BELOW RETROFIT COST ESTIMATION @ 95%** | | | | | | | | | | 7,122.56 |

Appendix H

| Description | Unit | Quantity | Material ($) | | Labor ($) | | Equipment ($) | | Total ($) | Net Cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Unit | Total | Unit | Total | Unit | Total | | |
| **REQUIRED RETROFITTING** | | | | | | | | | | |
| | | | | | | | | | | |
| **EXTERIOR FOUNDATION UNDERDRAIN** (Accounted for additional piping) | | | | | | | | | | |
| Pipe bedding, graded gravel 3/4" to 1/2" | CY | 105.00 | 1.32 | 138.60 | 0.54 | 74.84 | | | 213.44 | |
| | | | | | | | | | | 213.44 |
| **Option 3: Geocomposites (Hydraway 300)** | | | | | | | | | | |
| Single dimple | SF | 210.00 | 20.00 | 4,200.00 | | | | | 4,200.00 | |
| | | | | | | | | | | 4,200.00 |
| | | | | | | | | | | |
| **MAJOR/ ALTERNATIVE RETROFITTING TECHNIQUES** | | | | | | | | | | |
| **RESTORING CURRENT FOUNDATION WALL** | | | | | | | | | | |
| **Option 1: Grout Injection** | | | | | | | | | | |
| Grouting, 8" thick pumped, not including block | LF | 35.00 | 0.70 | 24.50 | 0.58 | 20.30 | 0.08 | 2.80 | 47.60 | |
| | | | | | | | | | | 47.60 |

Designation: C 62 – 87

American Association State Highway and Transportation Officials Standard
AASHTO No.: M 114-78

# Standard Specification for Building Brick (Solid Masonry Units Made From Clay or Shale)[1]

This standard is issued under the fixed designation C 62; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This specification has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.*

## 1. Scope

1.1 This specification covers brick intended for both structural and non-structural masonry where external appearance is not a requirement. The brick are prismatic units available in a variety of sizes, shapes, textures, and colors. This specification does not cover brick intended for use as facing units or where surface appearance is a requirement. (See Specification C 216).

1.2 Brick are manufactured from clay, shale, or similar naturally occurring earthy substances and subjected to a heat treatment at elevated temperatures (firing). The heat treatment must develop a fired bond between the particulate constituents to provide the strength and durability requirements of this Specification. (see firing, fired bond, and incipient fusion in Definitions C 43.)

1.3 Brick may be shaped during manufacture by molding, pressing, or extrusion, and the shaping method may be used to describe the brick (see Definitions C 43).

1.4 Three grades of brick are covered in this Specification.

1.5 The values stated in inch-pound units are to be regarded as the standard.

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 43 Definitions of Terms Relating to Structural Clay Products[2]

C 67 Methods of Sampling and Testing Brick and Structural Clay Tile[2]

C 216 Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)[2]

2.2 *ANSI Standards:*

A 62.3 Standard Sizes of Clay and Concrete Modular Masonry Units[3]

## 3. Physical Properties

3.1 *Appearance*—If brick are required to have a particular color, texture, finish, uniformity, or limits on cracks, warpage or other imperfections detracting from the appearance they should be purchased under Specification C 216.

3.2 *Durability*—The brick shall conform to the physical requirements for the grade specified, as prescribed in Table 2.

3.3 Unless otherwise specified by the purchaser, brick of Grades SW and MW shall be accepted instead of Grade NW, and Grade SW instead of Grade MW. When the grade is not specified, Grade MW shall govern.

3.4 The saturation coefficient requirement shall be waived provided the average cold water absorption of a random sample of five brick does not exceed 8 %, no more than one brick of the sample exceeds 8 % and its cold water absorption must be less than 10 %.

3.5 *Freezing and Thawing*—The requirements specified in 3.2 for water absorption (5-h boiling) and saturation coefficient shall be waived provided a sample of five brick, meeting all other requirements, complies with the following requirements when subjected to 50 cycles of the freezing-and-thawing test:[4]

Grade SW — No breakage and not greater than 0.5 % loss in dry weight of any individual brick.

[4] Brick are not required to conform to the provisions of 3.5, and these do not apply unless the sample fails to conform to the requirements for absorption and saturation coefficient prescribed in Table 1 or the absorption requirements in 3.4.

A particular lot or delivery shall be given the same grading as a previously tested lot, without repeating the freezing-and-thawing test, provided the brick are made by the same manufacturer from similar raw materials and by the same method of forming; and provided also that a sample of five brick selected from the particular lot has an average and individual minimum strength not less than a previously graded sample, and has average and individual maximum water absorption and saturation coefficient not greater than those of the previously tested sample graded in accordance with the freezing-and-thawing test.

TABLE 1 Grade Requirements for Face Exposures

| Exposure | Weathering Index (Note B) Less than 50 | 50 to 500 | 500 and greater |
|---|---|---|---|
| In vertical surfaces: | | | |
| In contact with earth | MW | SW | SW |
| Not in contact with earth | MW | SW | SW |
| In other than vertical surfaces: | | | |
| In contact with earth | SW | SW | SW |
| Not in contact with earth | MW | SW | SW |

[1] This specification is under the jurisdiction of ASTM Committee C-15 on Manufactured Masonry Units and is the direct responsibility of Subcommittee C15.02 on Clay Brick and Structural Clay Tile.

Current edition approved Feb. 10, 1987. Published April 1987. Originally published as C 62 – 27. Last previous edition C 62 – 85a.

[2] *Annual Book of ASTM Standards*, Vol 04.05.

[3] Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

TABLE 4 Tolerances on Dimensions

| Specified Dimension, in. (mm) | Maximum Permissible Variation from Specified Dimension, plus or minus, in. (mm) | |
|---|---|---|
| | Type FBX | Type FBS |
| 3 (76) and under | 1/16 (1.6) | 3/32 (2.4) |
| Over 3–4 (76 to 102), incl | 3/32 (2.4) | 1/8 (3.2) |
| Over 4–6 (102 to 152), incl | 1/8 (3.2) | 3/16 (4.7) |
| Over 6–8 (152 to 203), incl | 5/32 (4.0) | 1/4 (6.4) |
| Over 8–12 (203 to 305), incl | 7/32 (5.6) | 5/16 (7.9) |
| Over 12–16 (305 to 406), incl | 9/32 (7.1) | 3/8 (9.5) |

TABLE 5 Tolerances on Distortion

| Maximum Face Dimension, in. (mm) | Maximum Permissible Distortion, in. (mm) | |
|---|---|---|
| | Type FBX | Type FBS |
| 8 (203) and under | 1/16 (1.6) | 3/32 (2.4) |
| Over 8–12 (203 to 305), incl | 3/32 (2.4) | 1/8 (3.2) |
| Over 12–16 (305 to 406), incl | 1/8 (3.2) | 5/32 (4.0) |

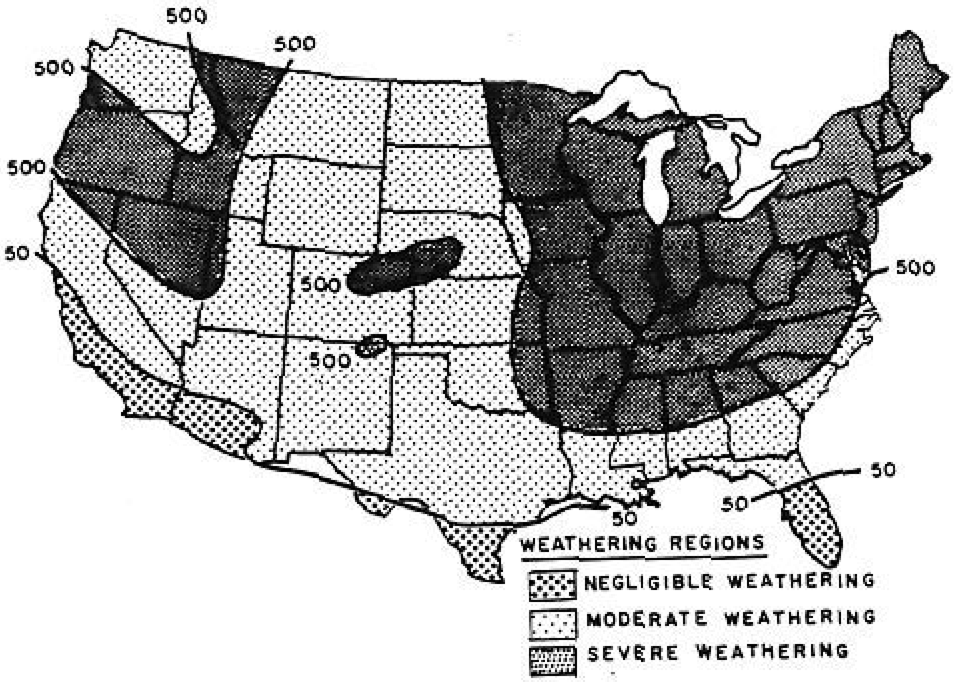



FIG. 1 Weathering Indexes in the United States

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*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.*

TABLE 3 *Permissible Variations in Dimensions*

NOTE—For a list of modular sizes, see American National Standard Sizes of Clay and Concrete Modular Masonry Units ANSI A62.3. All of the sizes listed in this standard are not produced in some parts of the United States, and purchasers should ascertain the size or sizes available.

| Specified dimension, in. (mm) | Maximum Permissible Variations from Specified Dimension, plus or minus, in. (mm) |
|---|---|
| Up to 3 (76), incl | 3/32 (2.4) |
| Over 3 to 4 (76 to 102), incl | 1/8 (3.2) |
| Over 4 to 6 (102 to 152), incl | 3/16 (4.8) |
| Over 6 to 8 (152 to 203), incl | 1/4 (6.4) |
| Over 8 to 12 (203 to 305), incl | 5/16 (7.9) |
| Over 12 to 16 (305 to 406), incl | 3/8 (9.5) |

strength or performance of the construction.

5.3 *Unless otherwise agreed upon by the purchaser* and the seller, a delivery of brick may contain not more than 5 % broken brick.

## 6. Sampling and Testing

6.1 For purpose of tests, brick that are representative of the commercial product shall be selected by a competent person appointed by the purchaser, the place or places of selection to be designated when the purchase order is placed. The manufacturer or the seller shall furnish specimens for tests without charge.

6.2 The brick shall be sampled and tested in accordance with Methods C 67.

NOTE—Unless otherwise specified in the purchase order, the cost of tests is typically borne as follows: If the results of the test show that the brick do not conform to the requirements of this specification, the cost is typically borne by the seller. If the results of the tests show that the brick do conform to the requirements of this specification, the cost is typically borne by the purchaser.

## EXPLANATORY NOTES

A. *Initial Rate of Absorption (Suction)* Both laboratory and field investigations have shown that strong and watertight joints between mortar and masonry units are not achieved by ordinary construction methods when the units as laid have excessive initial rates of absorption. Mortar that has stiffened somewhat because of loss of some mixing water to a unit does not make complete and intimate contact with the second unit, *resulting in poor adhesion, incomplete bond, and water-*permeable joints of low strength. Hence, the initial rate of absorption of the units should be determined by the method described in Section 9 of Methods C 67, if it is not known that it is less than 30 g/min per 30 $in.^2$ (194 $cm^2$). Units having initial rates of absorption exceeding 30 g/min per 30 $in.^2$ should be well wetted prior to laying. They may be wetted immediately before they are laid, but it is preferable to wet them thoroughly 3 to 24 h prior to their use so as to allow time for moisture to become distributed throughout the unit.

B. *Weathering Index* The effect of weathering on brick is related to the weathering index, which for any locality is the product of the average annual number of *freezing cycle days* and the average annual *winter rainfall* in inches (or millimetres), defined as follows:[4]

*A Freezing Cycle Day* is any day during which the air temperature passes either above or below 32°F (0°C). The average number of freezing cycle days in a year may be taken to equal the difference between the mean number of days during which the minimum temperature was 32°F or below and the mean number of days during which the maximum temperature was 32°F or below.

*Winter Rainfall* is the sum, in inches (or millimetres) of the mean monthly corrected precipitation (rainfall) occurring during the period between and including the normal date of the first killing frost in the fall and the normal date of the last killing frost in the spring. The winter rainfall for any period is equal to the total precipitation less one tenth of the total fall of snow, sleet, and hail. Rainfall for a portion of a month is prorated.

Figure 1 indicates general areas of the United States in which brick masonry is subject to severe, moderate, and negligible weathering. The severe weathering region has a weathering index greater than 500. The moderate weathering region has a weathering index of 50 to 500. The negligible weathering region has a weathering index of less than 50.

The use of Grade MW brick in a wall area above grade is structurally adequate in the severe weathering region, but Grade SW would provide a higher and more uniform degree *of resistance to frost action. The degree of* durability called for by Grade SW is not necessary for use in wall areas above grade in the moderate weathering region. Grade MW brick performs satisfactorily in wall areas above grade in the no-weathering region, where the average compressive strength of the units is at least 2500 psi (17.2 MPa) Grade SW brick should be used in any region when the units are in contact with the ground, in horizontal surfaces, or in any position where they are likely to be permeated with water.

[4] Data needed to determine the weathering index for any locality may be found or estimated from the tables of Local Climatological Data, published by the Weather Bureau, U. S. Department of Commerce.

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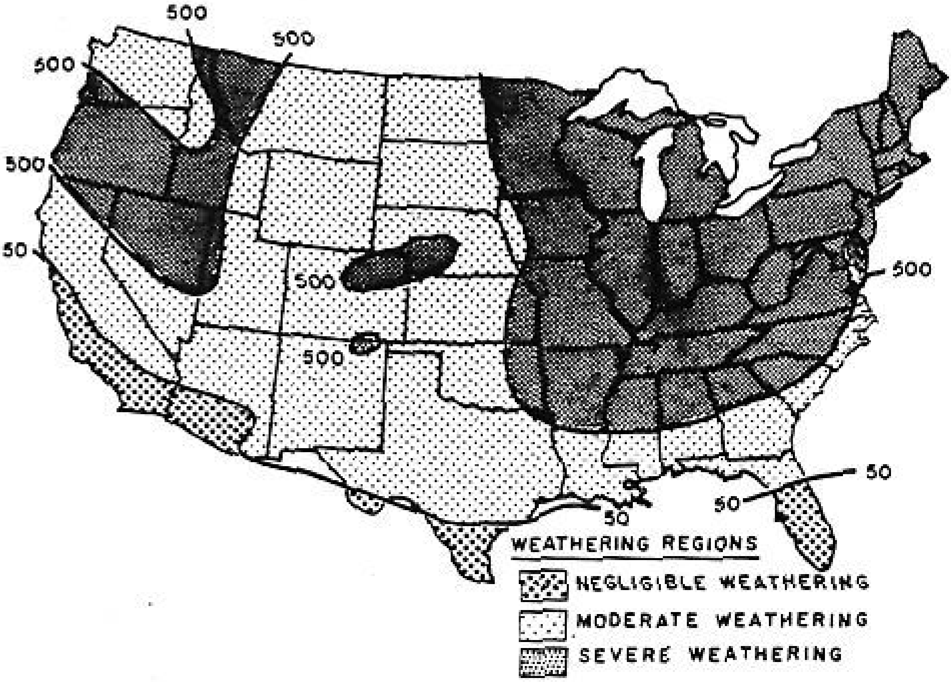


FIG. 1 Weathering Indexes in the United States

TABLE 2 Physical Requirements

| | Minimum Compressive Strength (brick flatwise), gross area, psi (MPa) | | Maximum Water Absorption by 5-h Boiling, % | | Maximum Saturation Coefficient[A] | |
|---|---|---|---|---|---|---|
| | Average of 5 Brick | Individual | Average of 5 Brick | Individual | Average of 5 Brick | Individual |
| SW | 3000 (20.7) | 2500 (17.2) | 17.0 | 20.0 | 0.78 | 0.80 |
| MW | 2500 (17.2) | 2200 (15.2) | 22.0 | 25.0 | 0.88 | 0.90 |
| NW | 1500 (10.3) | 1250 (8.6) | no limit | no limit | no limit | no limit |

...n coefficient is the ratio of absorption by 24-h submersion in cold water to that after 5-h submersion in boiling water.

...of *Absorption and Saturation Coefficient* ...If brick are intended for use exposed to ...the weathering index is less than 50 (see Fig. 1 ... Note B at the end of this specification), ... specified the requirements given in 3.2 for ...on (5-h boiling) and for saturation coefficient ...d and a minimum average strength require... (17.2 MPa) shall apply.

...When brick are required having strengths ...rescribed in Table 2, the purchaser should ...m strength.

...*sorption*—See Explanatory Notes.

...ring

... size of brick shall be as specified by the ...aximum permissible variation in dimen...al units shall not exceed those given in Table

...nless otherwise specified in the invitation ...ll be either solid or cored at the option of ...et cross-sectional area of cored brick in any ...the bearing surface shall be at least 75 % of ...ional area measured in the same plane. No part of any hole shall be less than ¾ in. (19.1 mm) from any edge of the brick.

4.3 *Frogging*—Unless otherwise specified in the invitation for bids, one bearing face of each brick may have a recess or panel (frog) not exceeding ⅜ in. (9.5 mm) in depth, except that in brick containing deep frogs any cross section through the frogs parallel to the bearing surface shall conform to the requirements of 4.2. No part of the recess shall be less than ¾ in. (19.1 mm) from any edge of the brick.

## 5. Visual Inspection

5.1 The brick, as delivered to the site, shall, by visual inspection, conform to the requirements specified by the purchaser or to the sample or samples approved as the standard of comparison and to the samples passing the tests for physical requirements. Minor indentations or surface cracks incidental to the usual method of manufacture, or the chipping resulting from the customary methods of handli... in shipment and delivery, should not be deemed groun... rejection.

5.2 The brick shall be free of defects, deficiencies, a... surface treatments, including coatings, that would interfere with the proper setting of the brick or significantly impair the units should be determined by the method described in Section 9 of Methods C 67, if it is not known that it is less than 30 g/min·30 in.$^2$ (30 g/min·194 cm$^2$). Units having initial rates of absorption exceeding 30 g/min·30 in.$^2$ should be well wetted prior to laying. They may be wetted immediately before they are laid, but it is preferable to wet them thoroughly 3 to 24 h prior to their use so as to allow time for moisture to become distributed throughout the unit.

NOTE 3—Purchasers should ascertain the type and sizes of brick available in the locality under consideration and should specify accordingly, stating a size and type represented by the available brick. In general, brick having a wide range of colors will require greater tolerance for the full range of colors than for a restricted range of colors.

NOTE 4—For a list of modular sizes, see the American National Standard Sizes of Clay and Concrete Modular Masonry Units: ANSI A62.3. Not all of the sizes listed in this standard are produced in some parts of the United States, and purchasers should ascertain the size or sizes available.

NOTE 5—When surface colored brick, other than sanded or flashed, are specified for *exterior* use, the purchaser should require that data be submitted showing that after 50 cycles of freezing thawing there is no observable difference in the applied finish when viewed from a distance of 10 ft (3.0 m) under an illumination of not less than 50 ft-candles (538 lx) by an observer with normal vision.

Service records of the performance of the particular coated brick in exterior locations may be accepted in place of the freezing and thawing test, upon consent of the purchaser.

**TABLE 1 Grade Requirements For Face Exposures**

| Exposure | Weathering Index (Note 1): Less than 50 | 50 to 500 | 500 and greater |
|---|---|---|---|
| In vertical surfaces: | | | |
| In contact with earth | MW | SW | SW |
| Not in contact with earth | MW | SW | SW |
| In other than vertical surfaces: | | | |
| In contact with earth | SW | SW | SW |
| Not in contact with earth | MW | SW | SW |

**TABLE 2 Physical Requirements**

| Designation | Minimum Compressive Strength (brick flatwise) psi, (MPa) gross area: Average of 5 brick | Individual | Maximum Water Absorption by 5-h Boiling, %: Average of 5 brick | Individual | Maximum Saturation Coefficient[A]: Average of 5 brick | Individual |
|---|---|---|---|---|---|---|
| Grade SW | 3000 (20.7) | 2500 (17.2) | 17.0 | 20.0 | 0.78 | 0.80 |
| Grade MW | 2500 (17.2) | 2200 (15.2) | 22.0 | 25.0 | 0.88 | 0.90 |

[A] The saturation coefficient is the ratio of absorption by 24-h submersion in cold water to that after 5-h submersion in boiling water.

**TABLE 3 Maximum Permissible Extent of Chippage From the Edges and Corners of Finished Face or Faces onto the Surface**

| Type | Percentage Allowed[A] | Chippage in in. (mm) in from: Edge | Corner | Percentage Allowed[A] | Chippage in in. (mm) in from: Edge | Corner |
|---|---|---|---|---|---|---|
| FBX | 5 % or less | 1/8–1/4 (3.2–6.4) | 1/4–3/8 (6.4–9.5) | 95 to 100 % | 0–1/8 (0–3.2) | 0–1/4 (0–6.4) |
| FBS[B] (Smooth) | 10 % or less | 1/4–5/16 (6.4–7.9) | 3/8–1/2 (9.5–12.7) | 90 to 100 % | 0–1/4 (0–6.4) | 0–3/8 (0–9.5) |
| FBS[C] (Rough) | 15 % or less | 5/16–7/16 (7.9–11.1) | 1/2–3/4 (12.7–19.1) | 85 to 100 % | 0–5/16 (0–7.9) | 0–1/2 (0–12.7) |
| FBA | as specified by the purchaser | | | | | |

[A] Percentage of exposed brick allowed in the wall with chips measured the listed dimensions in from an edge or corner.

[B] Smooth texture is the unbroken natural die finish.

[C] Rough texture is the finish produced when the face is sanded, combed, scratched, or scarified or the die skin on the face is entirely broken by mechanical means such as wire-cutting or wire-brushing.

vice—The reference temperature measuring device shall be a liquid-in-glass thermometer readable to 0.5°F (0.2°C) that has been verified and calibrated in accordance with Method E 77. The calibration certificate or report shall be available for inspection.

## 5. Calibration of Temperature Measuring Device

5.1 Each temperature measuring device used for determining temperature of freshly mixed concrete shall be calibrated annually, or whenever there is a question of accuracy. This calibration shall be performed by comparing the readings on the temperature measuring device at two temperatures at least 30°F (15°C) apart.

5.2 Calibration of the temperature measuring devices may be made in oil or other suitable baths having uniform density if provision is made to:

5.2.1 Maintain the bath temperature constant within 0.5°F (0.2°C) during the period of the test.

5.2.2 Have both the temperature and reference temperature measuring devices maintained in the bath for a minimum of 5 min before reading temperatures.

5.2.3 Continuously circulate the bath liquid to provide a uniform temperature.

5.2.4 Slightly tap thermometers containing liquid to avoid adhesion of the liquid to the glass if the temperature exposure is being reduced.

5.3 If a limiting temperature is specified, calibrate the measuring device at a temperature within ±5°F (2°C) of the limiting temperature permitted.

## 6. Sampling Concrete

6.1 The temperature of freshly mixed concrete may be measured in the transporting equipment provided the sensor of the temperature measuring device has at least 3 in. (75 mm) of concrete cover in all directions around it.

6.2 Temperature of the freshly mixed concrete may be obtained following concrete placement using the forms as the container.

6.3 If the transporting equipment or placement forms are not used as the container, a sample shall be prepared as follows:

6.3.1 Immediately, prior to sampling the freshly mixed concrete, dampen (with water) the sample container.

6.3.2 Sample the freshly mixed concrete in accordance with Method C 172, except that composite samples are not required if the only purpose for obtaining the sample is to determine temperature.

6.3.3 Place the freshly mixed concrete into the container.

6.3.4 When concrete contains a nominal maximum size of aggregate greater than 3 in. (75 mm), it may require 20 min before the temperature is stabilized after mixing.

## 7. Procedure

7.1 Place the temperature measuring device in the freshly mixed concrete so that the temperature sensing portion is submerged a minimum of 3 in. (75 mm). Gently press the concrete around the temperature measuring device at the surface of the concrete so that ambient air temperature does not affect the reading.

7.2 Leave the temperature measuring device in the freshly mixed concrete for a minimum period of 2 min or until the temperature reading stabilizes, then read and record the temperature.

7.3 Complete the temperature measurement of the freshly mixed concrete within 5 min after obtaining the sample.

## 8. Report

8.1 Record the measured temperature of the freshly mixed concrete to the nearest 1°F (0.5°C).

## 9. Precision and Bias

9.1 The precision and bias of this test method have not been determined. A precision and bias statement will be included when sufficient test data have been obtained and analyzed.



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American Association State Highway and Transportation
Officials Standard
AASHTO No.: T 32-70

# Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile[1]

*This standard is issued under the fixed designation C 67; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.*

*This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.*

## 1. Scope

1.1 These test methods cover procedures for the sampling and testing of brick and structural clay tile. Although not necessarily applicable to all types of units, tests include modulus of rupture, compressive strength, absorption, saturation coefficient, effect of freezing and thawing, efflorescence, initial rate of absorption and determination of weight, size, warpage, length change, and void area. (Additional methods of test pertinent to ceramic glazed facing tile are included in Specification C 126.)

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 43 Terminology of Structural Clay Products[2]

C 126 Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units[2]

C 150 Specification for Portland Cement[3]

E 4 Practices for Force Verification of Testing Machines[4]

E 6 Terminology Relating to Methods of Mechanical Testing[4]

## 3. Terminology

3.1 *Definitions:*

3.1.1 Terminology E 6 and Terminology C 43 shall be considered as applying to the terms used in these test methods.

## 4. Sampling

4.1 *Selection of Test Specimens*—For the purpose of these tests, full-size brick, tile, or solid masonry units shall be selected by the purchaser or by his authorized representative. Specimens shall be representative of the whole lot of units from which they are selected and shall include specimens representative of the complete range of colors, textures, and sizes in the shipment and shall be free of dirt, mud, mortar, or other foreign materials unassociated with the manufacturing process.

4.2 *Number of Specimens:*

4.2.1 *Brick*—For the modulus of rupture, compressive strength, abrasion resistance, and absorption determinations, at least ten individual brick shall be selected for lots of 1 000 000 brick or fraction thereof. For larger lots, five additional specimens shall be selected from each additional 500 000 brick or fraction thereof. Additional specimens may be taken at the discretion of the purchaser.

4.2.2 *Structural Clay Tile*—For the weight determination and for compressive strength and absorption tests, at least five tile shall be selected from each lot of 250 tons (226.8 Mg) or fraction thereof. For larger lots, five additional specimens shall be tested for each 500 tons (453.6 Mg) or fraction thereof. In no case shall less than five tile be taken. Additional specimens may be taken at the discretion of the purchaser.

4.3 *Identification*—Each specimen shall be marked so that it may be identified at any time. Markings shall cover not more than 5 % of the superficial area of the specimen.

4.4 *Weight Determination:*

4.4.1 *Drying*—Dry the test specimens in a ventilated oven at 230 to 239°F (110 to 115°C) for not less than 24 h and until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

4.4.2 *Cooling*—After drying, cool the specimens in a drying room maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %. Store the units free from drafts, unstacked, with separate placement, for a period of at least 4 h. Do not use specimens noticeably warm to the touch for any test requiring dry units.

4.4.2.1 An alternative method of cooling the specimens to approximate room temperature may be used as follows: Store units, unstacked, with separate placement, in a ventilated room for a period of 4 h, with a current of air from an electric fan passing over them for a period of at least 2 h.

4.4.3 *Calculations and Report:*

4.4.3.1 Calculate the weight per unit area of a specimen by dividing the total weight in pounds by the average area in square feet of the two faces of the unit as normally laid in a wall.

4.4.3.2 Report results separately for each unit with the average for five units or more.

4.5 *Removal of Silicone Coatings from Brick Units*—The silicone coatings intended to be removed by this process are any of the various polymeric organic silicone compounds used for water-resistant coatings of brick units. Heat the brick at 950 ± 50°F (510 ± 10°C) in an oxidizing atmosphere

[1] These test methods are under the jurisdiction of ASTM Committee C-15 on Manufactured Masonry Units and are the direct responsibility of Subcommittee C15.02 on Clay Brick and Structural Clay Tile.

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[2] *Annual Book of ASTM Standards*, Vol 04.05.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

for a period of not less than 3 h. The rate of heating and cooling shall not exceed 300°F (149°C) per h.

## 5. Modulus of Rupture (Flexure Test)

5.1 *Test Specimens*—The test specimens shall consist of whole dry full-size units (see 4.4.1). Five such specimens shall be tested.

5.2 *Procedure*:

5.2.1 Support the test specimen flatwise unless specified and reported otherwise (that is, apply the load in the direction of the depth of the unit) on a span approximately 1 in. (25.4 mm) less than the basic unit length and loaded at midspan. If the specimens have recesses (panels or depressions) place them so that such recesses are on the compression side. Apply the load to the upper surface of the specimen through a steel bearing plate ¼ in. (6.35 mm) in thickness and 1½ in. (38.10 mm) in width and of a length at least equal to the width of the specimen.

5.2.2 Make sure the supports for the test specimen are free to rotate in the longitudinal and transverse directions of the test specimen and adjust them so that they will exert no force in these directions.

5.2.3 *Speed of Testing*—The rate of loading shall not exceed 2000 lbf (8896 N)/min, but this requirement may be considered as being met if the speed of the moving head of the testing machine immediately prior to application of the load is not more than 0.05 in. (1.27 mm)/min.

5.3 *Calculation and Report*:

5.3.1 Calculate the modulus of rupture of each specimen as follows:

$$S = 3W(l/2 - x)/bd^2$$

where:

$S$ = modulus of rupture of the specimen at the plane of failure, lb/in.$^2$ (Pa),
$W$ = maximum load indicated by the testing machine, lbf (N),
$l$ = distance between the supports, in. (mm),
$b$ = net width, (face to face minus voids), of the specimen at the plane of failure, in. (mm),
$d$ = depth, (bed surface to bed surface), of the specimen at the plane of failure, in. (mm), and
$x$ = average distance from the midspan of the specimen to the plane of failure measured in the direction of the span along the centerline of the bed surface subjected to tension, in. (mm).

5.3.2 Report the average of the modulus of rupture determinations of all the specimens tested as the modulus of rupture of the lot.

## 6. Compressive Strength

6.1 *Test Specimens*:

6.1.1 *Brick*—The test specimens shall consist of dry half brick (see 4.4.1), the full height and width of the unit, with a length equal to one half the full length of the unit ±1 in. (25.4 mm), except as described below. If the test specimen, described above, exceeds the testing machine capacity, the test specimens shall consist of dry pieces of brick, the full height and width of the unit, with a length not less than one quarter of the full length of the unit, and with a gross cross-sectional area perpendicular to bearing not less than 14 in.$^2$ (90.3 cm$^2$). Test specimens shall be obtained by any method that will produce, without shattering or cracking, a specimen with approximately plane and parallel ends. Five specimens shall be tested.

6.1.2 *Structural Clay Tile*—Test five dry tile specimens in a bearing bed length equal to the width ± 1 in. (25.4 mm) or test full-size units.

6.2 *Capping Test Specimens*:

6.2.1 All specimens shall be dry and cool within the meaning of 4.4.1 and 4.4.2 before any portion of the capping procedure is carried out.

6.2.2 If the surface which will become bearing surfaces during the compression test are recessed or paneled, fill the depressions with a mortar composed of 1 part by weight of quick-hardening cement conforming to the requirements for Type III cement of Specification C 150, and 2 parts by weight of sand. Age the specimens at least 48 h before capping them. Where the recess exceeds ½ in. (12.7 mm), use a brick or tile slab section or metal plate as a core fill. Cap the test specimens using one of the two procedures described in 6.2.3 and 6.2.4.

6.2.3 *Gypsum Capping*—Coat the two opposite bearing surfaces of each specimen with shellac and allow to dry thoroughly. Bed one of the dry shellacked surfaces of the specimen in a thin coat of neat paste of calcined gypsum (plaster of paris) that has been spread on an oiled nonabsorbent plate, such as glass or machined metal. The casting surface plate shall be plane within 0.003 in. (0.076 mm) in 16 in. (406.4 mm) and sufficiently rigid; and so supported that it will not be measurably deflected during the capping operation. Lightly coat it with oil or other suitable material. Repeat this procedure with the other shellacked surface. Take care that the opposite bearing surfaces so formed will be approximately parallel and perpendicular to the vertical axis of the specimen and the thickness of the caps will be approximately the same and not exceeding ⅛ in. (3.18 mm). Age the caps at least 24 h before testing the specimens.

NOTE 1—A rapid-setting industrial type gypsum, such as Hydrostone or Hydrocal, is frequently used for capping.

6.2.4 *Sulfur-Filler Capping*—Use a mixture containing 40 to 60 weight % sulfur, the remainder being ground fire clay or other suitable inert material passing a No. 100 (150-µm) sieve with or without plasticizer. The casting surface plate requirements shall be as described in 6.2.3. Place four 1-in. (25.4-mm) square steel bars on the surface plate to form a rectangular mold approximately ½ in. (12.7 mm) greater in either inside dimension than the specimen. Heat the sulfur mixture in a thermostatically controlled heating pot to a temperature sufficient to maintain fluidity for a reasonable period of time after contact with the surface being capped. Take care to prevent overheating, and stir the liquid in the pot just before use. Fill the mold to a depth of ¼ in. (6.35 mm) with molten sulfur material. Place the surface of the unit to be capped quickly in the liquid, and hold the specimen so that its vertical axis is at right angles to the capping surface. The thickness of the caps shall be approximately the same. Allow the unit to remain undisturbed until solidification is complete. Allow the caps to cool for a minimum of 2 h before testing the specimens.

6.3 *Procedure*:



6.3.1 Test brick specimens flatwise (that is, the load shall be applied in the direction of the depth of the brick). Test structural clay tile specimens in a position such that the load is applied in the same direction as in service. Center the specimens under the spherical upper bearing within 1/16 in. (1.59 mm).

6.3.2 The testing machine shall conform to the requirements of Practices E 4.

6.3.3 The upper bearing shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall lie at the center of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to turn in any direction, and its perimeter shall have at least ¼ in. (6.35 mm) clearance from the head to allow for specimens whose bearing surfaces are not exactly parallel. The diameter of the bearing surface shall be at least 5 in. (127.00 mm). Use a hardened metal bearing block beneath the specimen to minimize wear of the lower platen of the machine. The bearing block surfaces intended for contact with the specimen should have a hardness not less than HRC60 (HB 620). These surfaces shall not depart from plane surfaces by more than 0.001 in. (0.03 mm). When the bearing area of the spherical bearing block is not sufficient to cover the area of the specimen, place a steel plate with surfaces machined to true planes within ± 0.001 in. (0.03 mm), and with a thickness equal to at least one third of the distance from the edge of the spherical bearing to the most distant corner between the spherical bearing block and the capped specimen.

6.3.4 *Speed of Testing*—Apply the load, up to one half of the expected maximum load, at any convenient rate, after which, adjust the controls of the machine so that the remaining load is applied at a uniform rate in not less than 1 nor more than 2 min.

6.4 *Calculation and Report*:

6.4.1 Calculate the compressive strength of each specimen as follows:

$$\text{Compressive strength, } C = W/A$$

where:

$C$ = compressive strength of the specimen, lb/in.$^2$ (or kg/cm$^2$) (or Pa·10$^4$)
$W$ = maximum load, lbf, (or kgf) (or N), indicated by the testing machine, and
$A$ = average of the gross areas of the upper and lower bearing surfaces of the specimen, in.$^2$ (or cm$^2$).

NOTE 2—When compressive strength is to be based on net area (example, clay floor tile), substitute for $A$ in the above formula the net area, in in.$^2$ (or cm$^2$), of the fired clay in the section of minimum area perpendicular to the direction of the load.

## 7. Absorption

7.1 *Accuracy of Weighings*:

7.1.1 *Brick*—The scale or balance used shall have a capacity of not less than 2000 g, and shall be sensitive to 0.5 g.

7.1.2 *Tile*—The balance used shall be sensitive to within 0.2 % of the weight of the smallest specimen tested.

7.2 *Test Specimens*:

7.2.1 *Brick*—The test specimens shall consist of half brick conforming to the requirements of 6.1.1. Five specimens shall be tested.

7.2.2 *Tile*—The specimens for the absorption test shall consist of five tile or three representative pieces from each of these five tile. If small pieces are used, take two from the shell and one from an interior web, the weight of each piece being not less than 227 g. The specimens shall have had their rough edges or loose particles ground off and, if taken from tile that have been subjected to compressive strength tests, specimens shall be free of cracks due to failure in compression.

7.3 *5-h and 24-h Submersion Tests*:

7.3.1 *Procedure*:

7.3.1.1 Dry and cool the test specimens in accordance with 4.4.1 and 4.4.2 and weigh each one.

7.3.1.2 *Saturation*—Submerge the dry, cooled specimen, without preliminary partial immersion, in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) for the specified time. Remove the specimen, wipe off the surface water with a damp cloth and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

7.3.2 *Calculation and Report*:

7.3.2.1 Calculate the absorption of each specimen as follows:

$$\text{Absorption, } \% = 100(W_s - W_d)/W_d$$

where:

$W_d$ = dry weight of the specimen, and
$W_s$ = saturated weight of the specimen after submersion in cold water.

7.3.2.2 Report the average absorption of all the specimens tested as the absorption of the lot.

7.4 *1-h, 2-h, and 5-h Boiling Tests*:

7.4.1 *Test Specimens*—The test specimens shall be the same five specimens used in the 5-h or 24-h cold-water submersion test where required and shall be used in the state of saturation existing at the completion of that test.

7.4.2 *Procedure*:

7.4.2.1 Return the specimen that has been subjected to the cold-water submersion to the bath, and subject it to the boiling test as described in 7.4.2.2.

7.4.2.2 Submerge the specimen in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) in such a manner that water can circulate freely on all sides of the specimen. Heat the water to boiling, within 1 h, boil continuously for specified time, and then allow to cool to 60 to 86°F (15.5 to 30°C) by natural loss of heat. Remove the specimen, wipe off the surface water with a damp cloth, and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

7.4.2.3 If the tank is equipped with a drain so that water at 60 to 86°F (15.5 to 30°C) can be passed through the tank continuously and at such a rate that a complete change of water takes place in not more than 2 min, make weighings at the end of 1 h.

7.4.3 *Calculation and Report*:

7.4.3.1 Calculate the absorption of each specimen as follows:

$$\text{Absorption, } \% = 100(W_b - W_d)/W_d$$

where:

$W_d$ = dry weight of the specimen, and

$W_b$ = saturated weight of the specimen after submersion in boiling water.

7.4.3.2 Report the average absorption of all the specimens tested as the absorption of the lot.

7.4.4 *Saturation Coefficient: Calculate the saturation coefficient of each specimen as follows:*

$$\text{Saturation coefficient} = W_{s24} - W_d / W_{b5} - W_d$$

where:

$W_d$ = dry weight of the specimen,

$W_{s24}$ = saturated weight of the specimen after 24-h submersion in cold water, and

$W_{b5}$ = saturated weight of the specimen after 5-h submersion in boiling water.

## 8. Freezing and Thawing

8.1 *Apparatus:*

8.1.1 *Compressor, Freezing Chamber, and Circulator* of such design and capacity that the temperature of the air in the freezing chamber will not exceed 16°F (−9°C) 1 h after introducing the maximum charge of units, initially at a temperature not exceeding 90°F (32°C).

8.1.2 *Trays and Containers*, shallow, metal, having an inside depth of 1½ ± ½ in. (38.1 ± 12.7 mm), and of suitable strength and size so that the tray with a charge of frozen units can be removed from the freezing chamber by one man.

8.1.3 *Balance*, having a capacity of not less than 2000 g and sensitive to 0.5 g.

8.1.4 *Drying Oven* that provides a free circulation of air through the oven and is capable of maintaining a temperature between 230 and 239°F (110 and 115°C).

8.1.5 *Thawing Tank* of such dimensions as to permit complete submersion of the specimens in their trays. Adequate means shall be provided so that the water in the tank may be kept at a temperature of 75 ± 10°F (24 ± 5.5°C).

8.1.6 *Drying Room*, maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %, and free from drafts.

8.2 *Test Specimens:*

8.2.1 *Brick*—The test specimens shall consist of half brick with approximately plane and parallel ends. If necessary, the rough ends may be smoothed by trimming off a thin section with a masonry saw. The specimens shall be free from shattering or unsoundness, visually observed, resulting from the flexure or from the absorption tests. Additionally, prepare specimens by removing all loosely adhering particles, sand or edge shards from the surface or cores. Test five specimens.

8.2.2 *Structural Clay Tile*—The test specimens shall consist of five tile or of a cell not less than 4 in. (101.6 mm) in length sawed from each of the five tile.

8.3 *Procedure:*

8.3.1 Dry and cool the test specimens as prescribed in 4.4.1 and 4.4.2 and weigh and record the dry weight of each.

8.3.2 Carefully examine each specimen for cracks. A crack is defined as a fissure or separation visible to a person with normal vision from a distance of one foot under an illumination of not less than 50 fc. Mark each crack its full length with an indelible felt marking pen.

8.3.3 Submerge the test specimens in the water of the thawing tank for 4 ± ½ h.

8.3.4 Remove the specimens from the thawing tank and stand them in the freezing trays with one of their head faces down. Head face is defined as the end surfaces of a whole rectangular brick (which have the smallest area). A space of at least ½ in. (12.7 mm) shall separate the specimens as placed in the tray. Pour sufficient water into the trays so that each specimen stands in ½ in. depth of water and then place the trays and their contents in the freezing chamber for 20 ± 1 h.

8.3.5 Remove the trays from the freezing chamber after 20 ± 1 h and totally immerse them and their contents in the water of the thawing tank for 4 ± ½ h.

8.3.6 Freeze the test specimens by the procedure in 8.3.4 one cycle each day of the normal work week. Following the 4 ± ½ h thawing after the last freeze-thaw cycle of the normal work week, remove the specimens from the trays and store them for 44 ± 1 h in the drying room. Do not stack or pile units. Provide a space of at least 1 in. (25.4 mm) between all specimens. Following this period of air drying, inspect the specimens, submerge them in the water of the thawing tank for 4 ± ½ h, and again subject them to a normal week of freezing and thawing cycles in accordance with 8.3.4 and 8.3.5. If a laboratory has personnel available for testing 7 days a week, the requirement for storing the specimens for 44 ± 1 h in the drying room following the 4 ± ½ h thawing after the last freezing cycle of the week may be waived. The specimens may then be subjected to 50 cycles of freezing and thawing on 50 consecutive days. When a normal 5-day work week is interrupted, put specimens into a drying cycle which may extend past the 44 ± 1 h drying time outlined in the procedures of this section.

8.3.7 Continue the alternations of drying and submersion in water for 4 ± ½ h, followed by 5 cycles of freezing and thawing or the number of cycles needed to complete a normal work week, until a total of 50 cycles of freezing and thawing has been completed. Stop the test if the test specimen has been broken or appears to have lost more than 3 % of its original weight as judged by visual inspection.

8.3.8 After completion of 50 cycles, or when the test specimen has been withdrawn from test as a result of disintegration, dry and weigh the specimen as prescribed in 8.3.1.

8.4 *Calculations, Examination, Rating and Report:*

8.4.1 *Calculation*—Calculate the loss in weight as a percentage of the original weight of the dried specimen.

8.4.2 *Examination*—Reexamine the surface of the specimens for cracks (see 8.3.2) and record the presence of any new cracks developed during the freezing-thawing testing procedure. Measure and record the length of the new cracks.

8.4.3 *Rating*—A specimen is considered to fail the freezing and thawing test under any one of three circumstances:

8.4.3.1 Weight Loss—A weight loss of greater than 0.5 %.

8.4.3.2 Breakage—The specimen separates into two or more significant pieces, or

8.4.3.3 Cracking—A specimen develops a crack during the freezing and thawing procedure that exceeds in length the minimum dimension of the specimen.

If none of the above circumstances occur, the specimens are considered to pass the freezing and thawing test.

8.4.4 *Report*—The report shall state whether the sample passed or failed the test. Any failures shall include the rating and the reason for classification as a failure and the number of cycles causing failure in the event failure occurs prior to 50 cycles.

## 9. Initial Rate of Absorption (Suction) (Laboratory Test)

9.1 *Apparatus:*

9.1.1 *Trays or Containers*—Watertight trays or containers, having an inside depth of not less than ½ in. (12.7 mm), and of such length and width that an area of not less than 300 in.² (1935.5 cm.²) of water surface is provided. The bottom of the tray shall provide a plane, horizontal upper surface, when suitably supported, so that an area not less than 8 in. (203.2 mm) in length by 6 in. (152.4 mm) in width will be level when tested by a spirit level.

9.1.2 *Supports for Brick*—Two noncorrodible metal supports consisting of bars between 5 and 6 in. (127.00 and 152.5 mm) in length, having triangular, half-round, or rectangular cross sections such that the thickness (height) will be approximately ¼ in. (6.35 mm). The thickness of the two bars shall agree within 0.001 in. (0.03 mm) and, if the bars are rectangular in cross section, their width shall not exceed 1/16 in. (1.94 mm).

9.1.3 *Means for Maintaining Constant Water Level*—Suitable means for controlling the water level above the upper surface of the supports for the brick within ± 0.01 in. (0.25 mm) (see Note 3), including means for adding water to the tray at a rate corresponding to the rate of removal by the brick undergoing test (see Note 4). For use in checking the adequacy of the method of controlling the rate of flow of the added water, a reference brick or half brick shall be provided whose displacement in ⅛ in. (3.18 mm) of water corresponds to the brick or half brick to be tested within ± 2.5 %. Completely submerge the reference brick in water for not less than 3 h preceding its use.

NOTE 3—A suitable means for obtaining accuracy in control of the water level may be provided by attaching to the end of one of the bars two stiff metal wires that project upward and return, terminating in points, one of which is ⅛ − 0.01 in. (3.18 − 0.25 mm) and the other ⅛ + 0.01 in. (3.18 + 0.25 mm) above the upper surface or edge of the bar. Such precise adjustment is obtainable by the use of depth plates or a micrometer microscope. When the water level with respect to the upper surface or edge of the bar is adjusted so that the lower point dimples the water surface when viewed by reflected light and the upper point is not in contact with the water, the water level is within the limits specified. Any other suitable means for fixing and maintaining a constant depth of immersion may be used if equivalent accuracy is obtained. As an example of such other suitable means, there may be mentioned the use of rigid supports movable with respect to the water level.

NOTE 4—A rubber tube leading from a siphon or gravity feed and closed by a spring clip will provide a suitable manual control. The so-called "chicken-feed" devices as a rule lack sensitivity and do not operate with the very small changes in water level permissible in this test.

9.1.4 *Balance*, having a capacity of not less than 3000 g and sensitive to 0.5 g.

9.1.5 *Drying Oven*, conforming to the requirements of 8.1.4.

9.1.6 *Constant-Temperature Room*, maintained at a temperature of 70 ± 2.5°F (21 ± 1.4°C).

9.1.7 *Timing Device*—A suitable timing device, preferably a stop watch or stop clock, which shall indicate a time of 1 min to the nearest 1 s.





9.2 *Test Specimens*, consisting of whole brick. Five specimens shall be tested.

9.3 *Procedure:*

9.3.1 Dry and cool the test specimens in accordance with one of the following procedures.

9.3.1.1 *Oven-dried Procedure*—Dry and cool the test specimens in accordance with 4.4.1 and 4.4.2.

9.3.1.2 *Ambient Air-dried Procedure*—Store units unstacked, with separate placement in a ventilated room maintained at a temperature of 75 ± 15°F (24 ± 8°C) with a relative humidity between 30 % and 70 % for a period of 4 h, with a current of air from an electric fan passing over them for a period of at least 2 h. Continue until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

9.3.2 Measure to the nearest 0.05 in. (1.27 mm) the length and width of the flatwise surface of the test specimen of rectangular units or determine the area of other shapes to similar accuracy that will be in contact with the water. Weigh the specimen to the nearest 0.5 g.

9.3.3 Adjust the position of the tray for the absorption test so that the upper surface of its bottom will be level when tested by a spirit level, and set the saturated reference brick (9.1.3) in place on top of the supports. Add water until the water level is ⅛ ± 0.01 in. (3.18 ± 0.25 mm) above the top of the supports. When testing tile with scored bed surfaces, the depth of water level is ⅛ ± 0.01 in. plus the depth of scores.

9.3.4 After removal of the reference brick, set the test brick in place flatwise, counting zero time as the moment of contact of the brick with the water. During the period of contact (1 min ± 1 s) keep the water level within the prescribed limits by adding water as required. At the end of 1 min ± 1 s, lift the brick from contact with the water, wipe off the surface water with a damp cloth, and reweigh the brick to the nearest 0.5 g. Wiping shall be completed within 10 s of removal from contact with the water, and weighing shall be completed within 2 min.

NOTE 5—Place the brick in contact with the water quickly, but without splashing. Set the brick in position with a rocking motion to avoid the entrapping of air on its under surface. Test brick with frogs or depressions in one flatwise surface with the frog or depression uppermost.

9.4 *Calculation and Report:*

9.4.1 The difference in weight in grams between the initial and final weighings is the weight in grams of water absorbed by the brick during 1-min contact with the water. If the area of its flatwise surface (length times width) does not differ more than ± 0.75 in.² (4.84 cm²) (±2.5 %) from 30 in.² (193.55 cm²), report the gain in weight in grams as the initial rate of absorption in 1 min.

9.4.2 If the area of its flatwise surface differs more than ± 0.75 in.² (4.84 cm²) (±2.5 %) from 30 in.² (193.55 cm²), calculate the equivalent gain in weight from 30 in.² (193.55 cm²) as follows:

$$X = 30W/LB \quad (\text{metric } X = 193.55\ W/LB)$$

where:

$X$ = gain in weight corrected to basis of 30 in.² (193.55 cm²) flatwise area,

$W$ = actual gain in weight of specimen, g.

**2.1.8.5.1.2** The ends of single leg or U-stirrups shall be anchored by one of the following means:

(a) A standard hook plus an effective embedment of 0.5 $l_d$. The effective embedment of a stirrup leg shall be taken as the distance between the middepth of the member $d/2$ and the start of the hook (point of tangency).

(b) For No. 5 bar (M #16) and D31 (MD200) wire and smaller, bending around longitudinal reinforcement through at least 135 degrees plus an embedment of 0.33 $l_d$. The 0.33 $l_d$ embedment of a stirrup leg shall be taken as the distance between middepth of member $d/2$ and start of hook (point of tangency).

**2.1.8.5.1.3** Between the anchored ends, each bend in the continuous portion of a transverse U-stirrup shall enclose a longitudinal bar.

**2.1.8.5.1.4** Longitudinal bars bent to act as shear reinforcement, where extended into a region of tension, shall be continuous with longitudinal reinforcement and, where extended into a region of compression, shall be developed beyond middepth of the member $d/2$.

**2.1.8.5.1.5** Pairs of U-stirrups or ties placed to form a closed unit shall be considered properly spliced when length of laps are 1.7 $l_d$. In grout at least 18 in. (457 mm) deep, such splices with $A_v f_y$ not more than 9,000 lb (40 032 N) per leg may be considered adequate if legs extend the full available depth of grout.

**2.1.8.5.2** *Welded wire fabric*

**2.1.8.5.2.1** For each leg of welded wire fabric forming simple U -stirrups, there shall be either:

(a) Two longitudinal wires at a 2 in. (50.8 mm) spacing along the member at the top of the U, or

(b) One longitudinal wire located not more than $d/4$ from the compression face and a second wire closer to the compression face and spaced not less than 2 in. (50.8 mm) from the first wire. The second wire shall be located on the stirrup leg beyond a bend, or on a bend with an inside diameter of bend not less than $8d_b$.

**2.1.8.5.2.2** For each end of a single leg stirrup of welded smooth or deformed wire fabric, there shall be two longitudinal wires spaced a minimum of 2 in. (50.8 mm) with the inner wire placed at a distance at least $d/4$ or 2 in. (50.8 mm) from middepth of member $d/2$. Outer longitudinal wire at tension face shall not be farther from the face than the portion of primary flexural reinforcement closest to the face.

**2.1.8.6** *Splices of reinforcement*-----Lap splices, welded splices, or mechanical connections are permitted in accordance with the provisions of this section. All welding shall conform to AWS D1.4.

**2.1.8.6.1** *Lap splices*

**2.1.8.6.1.1** The minimum length of lap for bars in tension or compression shall be determined by Eq. (2-9), but not less than 12 in. (305 mm).

$$l_d = 0.002 d_b F_s \tag{2-9}$$

When epoxy-coated bars are used, lap length determined by Eq. (2-9) shall be increased by 50 percent.

**2.1.8.6.1.2** Bars spliced by noncontact lap splices shall not be spaced transversel farther apart than one-fifth the required length of lap nor more than 8 in. (203 mm).

**2.1.8.6.2** *Welded splices*----Welded splices shall have the bars butted and welded to develop in tension at least 125 percent of the specified yield strength of the bar.

**2.1.8.6.3** *Mechanical connections* — Mechanical connections shall have the bars connected to develop in tension or compression, as required, at least 125 percent of the specified yield strength of the bar.

**2.1.8.6.4** *End-bearing splices*

**2.1.8.6.4.1** In bars required for compression only, the transmission of compressive stress by bearing of square cut ends held in concentric contact by a suitable device is permitted.

**2.1.8.6.4.2** Bar ends shall terminate in flat surfaces within $1\,^1/_2$ degree of a right angle to the axis of the bars and shall be fitted within 3 degrees of full bearing after assembly.

**2.1.8.6.4.3** End-bearing splices shall be used only in members containing closed ties, closed stirrups, or spirals.

## 2.2 — Unreinforced masonry

**2.2.1** *Scope*

**2.2.1.1** This section covers requirements for unreinforced masonry as defined in Section 1.6, except as otherwise indicated in Section 2.2.4.

**2.2.1.2** The provisions of this section are to be applied in conjunction with the provisions of Chapter 1 and Section 2.1.

**2.2.2** *Stresses in reinforcement*

The effect of stresses in reinforcement shall be neglected.

**2.2.3** *Axial compression and flexure*

**2.2.3.1** Members subjected to axial compression, flexure, or to combined axial compression and flexure shall be designed to satisf Eq. (2-10) and Eq. (2-11).

$$\frac{f_a}{F_a}+\frac{f_b}{F_b}\leq 1 \quad (2\text{-}10)$$

$$P\leq\left(\tfrac{1}{4}\right)P_e \quad (2\text{-}11)$$

where:

(a) For members having an $h/r$ ratio not greater than 99:

$$F_a=\left(\tfrac{1}{4}\right)f'_m\left[1-\left(\frac{h}{140r}\right)^2\right] \quad (2\text{-}12)$$

(b) For members having an $h/r$ ratio greater than 99:

$$F_a=\left(\tfrac{1}{4}\right)f'_m\left(\frac{70r}{h}\right)^2 \quad (2\text{-}13)$$

(c) $$F_b=\left(\tfrac{1}{3}\right)f'_m \quad (2\text{-}14)$$

(d) $$P_e=\frac{\pi^2E_mI}{h^2}\left(1-0.577\frac{e}{r}\right)^3 \quad (2\text{-}15)$$

**2.2.3.2** Allowable tensile stresses due to flexure transverse to the plane of masonry member shall be in accordance with the values in Table 2.2.3.2.

**2.2.4** *Axial tension*

The tensile strength of masonry shall be neglected in design when the masonry is subjected to axial tension forces.

**2.2.5** *Shear*

**2.2.5.1** Shear stresses due to forces acting in the direction considered shall be computed in accordance with Section 1.9.1 and determined b Eq. (2-16).

$$f_v = \frac{VQ}{Ib} \quad (2\text{-}16)$$

**2.2.5.2** In-plane shear stresses shall not exceed any of:

(a) $1.5\sqrt{f'_m}$

(b) 120 psi (827 kPa)

(c) $v + 0.45\,N_v/A_n$

where v:

= 37 psi (255 kPa) for masonry in running bond that is not grouted solid, or

= 37 psi (255 kPa) for masonry in other than running bond with open end units that are grouted solid, or

= 60 psi (414 kPa) for masonry in running bond that is grouted solid

(d) 15 psi (103 kPa) for masonry in other than running bond with other than open end units that are grouted solid.

**Table 2.2.3.2 — Allowable flexural tension for clay and concrete masonry, psi (kPa)**

| Masonry type | Mortar types | | | |
|---|---|---|---|---|
| | Portland cement/lime or mortar cement | | Masonry cement or air entrained portland cement/lime | |
| | M or S | N | M or S | N |
| Normal to bed joints | | | | |
| Solid units | 40 (276) | 30 (207) | 24 (166) | 15 (103) |
| Hollow units[1] | | | | |
| Ungrouted | 25 (172) | 19 (131) | 15 (103) | 9 (62) |
| Fully grouted | 68 (469) | 58 (400) | 41 (283) | 29 (200) |
| Parallel to bed joints in running bond | | | | |
| Solid units | 80 (552) | 60 (414) | 48 (331) | 30 (207) |
| Hollow units | | | | |
| Ungrouted and partially grouted | 50 (345) | 38 (262) | 30 (207) | 19 (131) |
| Fully grouted | 80 (552) | 60 (414) | 48 (331) | 30 (207)) |

[1] For partially grouted masonry, allowable stresses shall be determined on the basis of linear interpolation between hollow units that are fully grouted and ungrouted hollow units based on amount of grouting.

**2.2.5.3** Shear stresses shall not exceed the requirements of Section 2.1.3.2.2 at interfaces between wythes and filled collar joints or between wythes and headers.

## 2.3 — Reinforced masonry

**2.3.1** *Scope*

**2.3.1.1** *This section covers requirements for* the design of structures neglecting the contribution of tensile strength of masonry, except as provided in Section 2.3.5.

**2.3.1.2** The provisions of this section are to be applied in conjunction with the general requirements of Chapter 1 and Section 2.1.

**2.3.2** *Steel reinforcement Allowable stresses*

**2.3.2.1** *Tension* — Tensile stress in reinforcement shall not exceed the following:

(a) Grade 40 or Grade 50 reinforcement ......................................... 20,000 psi (137.9 MPa)
(b) Grade 60 reinforcement .......24,000 psi (165.5 MPa)
(c) Wire joint reinforcement .....30,000 psi (206.9 Mpa)

**2.3.2.2** *Compression*

**2.3.2.2.1** The compressive resistance of steel reinforcement shall be neglected unless lateral reinforcement is provided in compliance with the requirements of Section 2.1.4.6.

**2.3.2.2.2** Compressive stress in reinforcement shall not exceed the lesser of 0.4 $f_y$ or 24,000 psi (165.5 MPa).

**2.3.3** *Axial compression and flexure*

**2.3.3.1** Members subjected to axial compression, flexure, or to combined axial compression and flexure shall be designed in compliance with Sections 2.3.3.2 through 2.3.3.4.

**2.3.3.2** *Allowable forces and stresses*

**2.3.3.2.1** The compressive force in reinforced masonry due to axial load only shall not exceed that given b Eq. (2-17) or Eq. (2-18):

(a) For members having an *h/r* ratio not greater than 99:

$$P_a = (0.25 f'_m A_n + 0.65 A_{st} F_s)\left[1 - \left(\frac{h}{140r}\right)^2\right] \quad (2\text{-}17)$$

(b) For members having an *h/r* ratio greater than 99:

$$P_a = (0.25 f'_m A_n + 0.65 A_{st} F_s)\left(\frac{70r}{h}\right)^2 \quad (2\text{-}18)$$

**2.3.3.2.2** The compressive stress in masonry due to flexure or due to flexure in combination with axial load shall not exceed ($^1/_3$) $f'_m$ provided the calculated compressive stress due to the axial load component, $f_a$, does not exceed the allowable stress, $F_a$, in Section 2.2.3.2.1.

**2.3.3.3** *Effective compressive width per bar*

**2.3.3.3.1** In running bond masonry, and masonry in other than running bond with bond beams spaced not more than 48 in. (1219 mm) center-to-center, the width of the compression area used in stress calculations shall not exceed the least of:

(a) Center-to-center bar spacing.
(b) Six times the wall thickness.
(c) 72 in. (1829 mm).

**2.3.3.3.2** In masonry in other than running bond, with bond beams spaced more than 48 in. (1219 mm) center-to-center, the width of the compression area used in stress calculations shall not exceed the length of the masonry unit.

**2.3.3.4** *Beams*

**2.3.3.4.1** Span length of members not built integrally with supports shall be taken as the clear span plus depth of member, but need not exceed the distance between centers of supports.

**2.3.3.4.2** In analysis of members that are continuous over supports for determination of moments, span length shall be taken as the distance between centers of supports.

**2.3.3.4.3** Length of bearing of beams on their supports shall be a minimum of 4 in. (102 mm) in the direction of span.

**2.3.3.4.4** The compression face of beams shall be laterally supported at a maximum spacing of 32 times the beam thickness.

**2.3.3.4.5** Beams shall be designed to meet the deflection requirements of Section 1.10.1.

**2.3.4** *Axial tension and flexural tension*

Axial tension and flexural tension shall be resisted entirely by steel reinforcement.

**2.3.5** *Shear*

**2.3.5.1** Members which are not subjected to flexural tension shall be designed in accordance with the requirements of Section 2.2.5 or shall be designed in accordance with the following:

**2.3.5.1.1** Reinforcement shall be provided in accordance with the requirements of Section 2.3.5.3.

**2.3.5.1.2** The calculated shear stress, $f_v$, shall not exceed $F_v$, where $F_v$ is determined in accordance with Section 2.3.5.2.3.

**2.3.5.2** Members subjected to flexural tension shall be reinforced to resist the tension and shall be designed in accordance with the following:

**2.3.5.2.1** Calculated shear stress in the masonry shall be determined by the relationship:

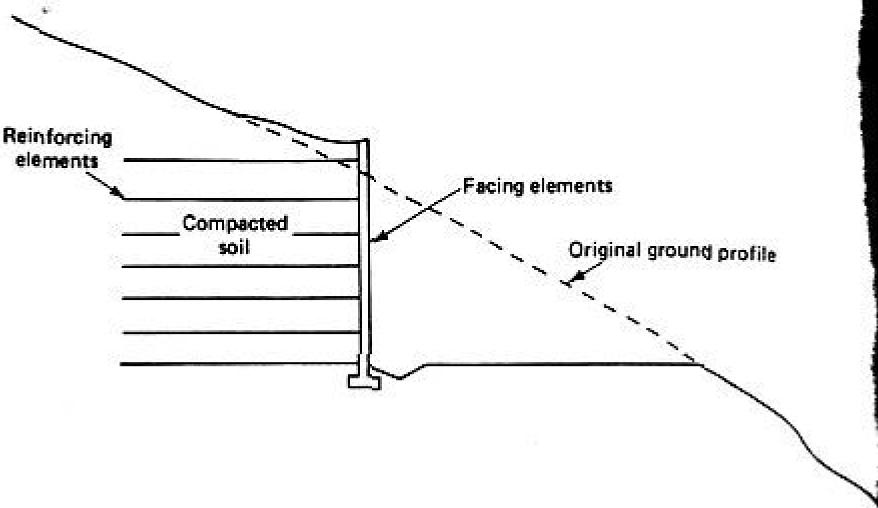



**FIGURE 10–17** Soil reinforcement.

## Preventing Embankment Failure

An analysis of the causes of excavation slope failure described above will cate methods that can be used to prevent such failures. Side slopes m stabilized by cutting them back to an angle equal to or less than the an repose of the soil, or by providing lateral support for the excavation a cussed in Section 10–7. Both side and bottom stability may be increa dewatering the soil surrounding the excavation. Methods for dewaterin protecting excavations are described in the following sections.

To protect more permanent slopes, such as highway cuts, retaining are often used. Slopes of cohesive soil may be strengthened by increasin shearing resistance along the potential slip plane. This may be done by ving piles or inserting stone columns into the soil across the potential plane. Another technique for reinforcing slopes is called *soil* (or earth) *forcement.* One form of this process is known under the trademark Reinforced Earth. As shown in Figure 10–17, soil reinforcement in embedding high-tensile-strength nonbiodegradable elements in a comp soil mass. The embedded tensile elements are attached to facing mat usually of concrete or timber, to prevent erosion or raveling of soil at th surface. Soil reinforcement is often a less expensive method for stab slopes than is the construction of conventional retaining walls.

## 10–7 PROTECTING EXCAVATIONS AND WORKERS

Excavation cave-ins are responsible for the greatest number of U.S. co tion fatalities, accounting for over 300 deaths during a recent year. of the frequency and severity of cave-in accidents, OSHA has estab r of safety regulations affecting excavation operations. While it may be le to avoid placing workers into an excavation through the use of e-controlled equipment or robots (see Chapter 20), in most cases work- st enter the excavation and OSHA regulations will apply. These regu- s require, among other things, that workers in an excavation be pro- d from cave-ins by one of the following methods:

- Sloping or benching of the sides of the excavation.
- Supporting the sides of the excavation by shoring.
- Placing a shield between workers and the sides of the excavation.

ly exceptions to these requirements are when the excavation is made y in stable rock, or the excavation is less than 5 ft (1.524 m) in depth mination of the ground by a competent person provides no indication tential cave-in. As defined by OSHA, *competent person* means one who ble of identifying existing and predictable hazards in the surround- g working conditions which are unsanitary, hazardous, or dangerous to yees, and who has authorization to take prompt corrective measures to ate them.

o comply with OSHA rules on sloping, shoring, and shielding, it is nec- y to be familiar with the OSHA Soil and Rock Classification System n in Table 10–1. In this system, soil and rock are classified as Stable , Type A, Type B, or Type C.

## ping and Benching

r OSHA rules, when workers are required to be in an excavation the um allowable steepness of the sides of excavations less than 20 ft (6.1 ) when employing a simple uniform slope is given in Table 10–2. How- note the exceptions shown in the footnote to the table.

The requirements for benching (stepping) of excavation sides and for g when layered soils of different types are involved are given in refer- . Sloping or benching for excavations greater than 20 ft (6.1 m) deep e designed by a registered professional engineer. The major disadvan- f sloping or benching of excavation sides is the space required for the tion plus side slopes.

## ng and Shielding

support for the sides of an excavation is usually provided by *shoring*. g system that completely encloses an excavation is essentially a cof- which is a structure designed to keep water and/or soil out of an exca- rea. A caisson is also a form of cofferdam, as we have seen. Common f shoring systems include timber shoring, aluminum hydraulic , lagging, and sheet piling. Shoring and shielding systems must be d in compliance with OSHA tables, manufacturer's tabulated data, or gned by a registered professional engineer.

**TABLE 10–1**
**OSHA Soil and Rock Classification System**

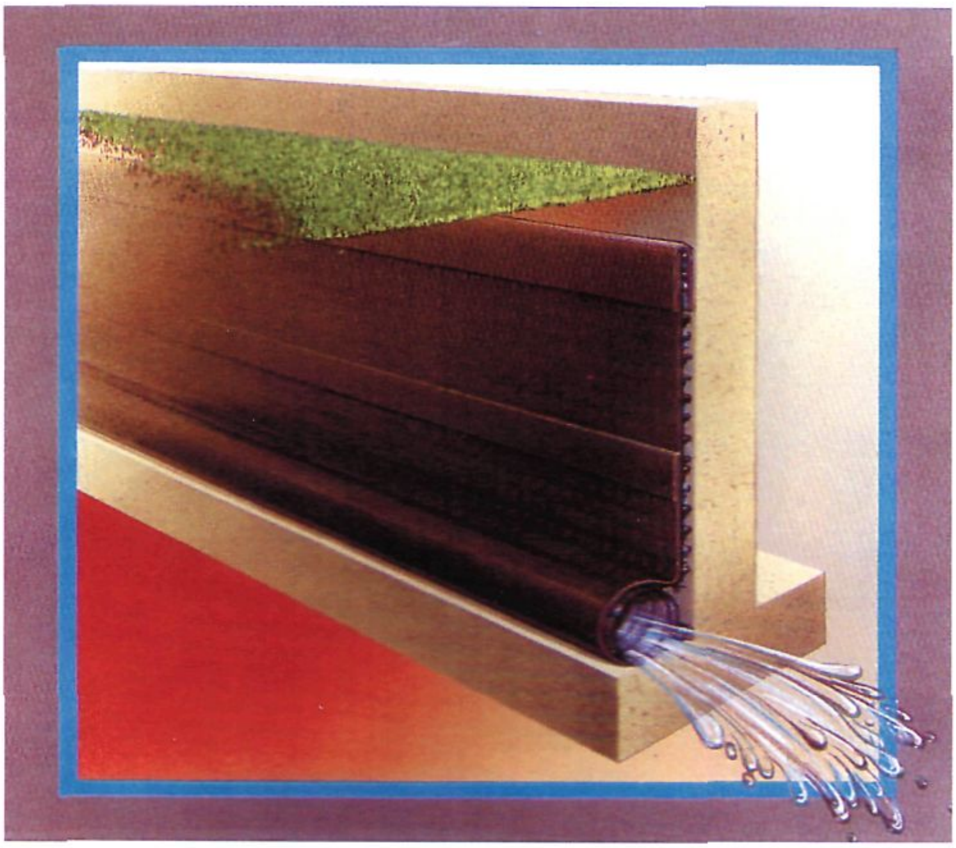
| Stable Rock | Type A | Type B | Type C |
|---|---|---|---|
| Stable rock means natural solid mineral matter that can be excavated with vertical sides and remain intact while exposed. | Type A means cohesive soil with an unconfined compressive strength of 1.5 tsf (144 kPa) or greater. Examples of cohesive soils are: clay, silty clay, sandy clay, clay loam and, in some cases, silty clay loam and sandy clay loam. Cemented soils such as caliche and hardpan are also considered Type A if:<br>i. The soil is fissured; or<br>ii. The soil is subject to vibration from heavy traffic, pile driving, or similar effects; or<br>iii. The soil has been previously disturbed; or<br>iv. The soil is part of a *sloped, layered system* where the layers dip into the excavation on a slope of four horizontal to one vertical (4H:1V) or greater; or<br>v. The material is subject to other factors that would require it to be classified as a less stable material. | Type B means:<br>i. Cohesive soil with an unconfined compressive strength greater than 0.5 tsf (48 kPa) but less than 1.5 tsf (144 kPa); or<br>ii. Granular cohesionless soils including angular gravel (similar to crushed rock), silt, silt loam, sandy loam and, in some cases, silty clay loam and sandy clay loam.<br>iii. Previously disturbed soils except those which would otherwise be classed as Type C soil.<br>iv. Soil that meets the unconfined compressive strength or cementation requirements for Type A, but is fissured or subject to vibration; or<br>v. Dry rock that is not stable; or<br>vi. Material that is part of a sloped, layered system where the layers dip into the excavation on a slope less steep than four horizontal to one vertical (4H:1V), but only if the material would otherwise be classified as Type B. | Type C means:<br>i. Cohesive soil with an unconfined compressive strength of 0.5 tsf (48 kPa) or less; or<br>ii. Granular soils including gravel, sand, and loamy sand; or<br>iii. Submerged soil or soil from which water is freely seeping; or<br>iv. Submerged rock that is not stable; or<br>v. Material in a sloped, layered system where the layers dip into the excavation on a slope of four horizontal to one vertical (4H:1V) or steeper. |

**TABLE 10–2**
**OSHA maximum allowable slopes for excavation sides**

| Soil or Rock Type | Maximum Allowable Slope (H:V) For Excavations Less Than 20 ft (6.1 m) Deep |
|---|---|
| Stable Rock | Vertical (90°) |
| Type A* | 3/4:1 (53°) |
| Type B | 1:1 (45°) |
| Type C | 1-1/2:1 (34°) |

*A short-term (24 h or less) maximum allowable slope of 1/2H:1V (63°) is allowed in excavations in Type A soil that are 12 ft (3.67 m) or less in depth. Short-term maximum allowable slopes for excavations greater than 12 ft (3.67 m) in depth shall be 3/4H:1V (53°).

Solutia: Hydraway 300 Geocomposite



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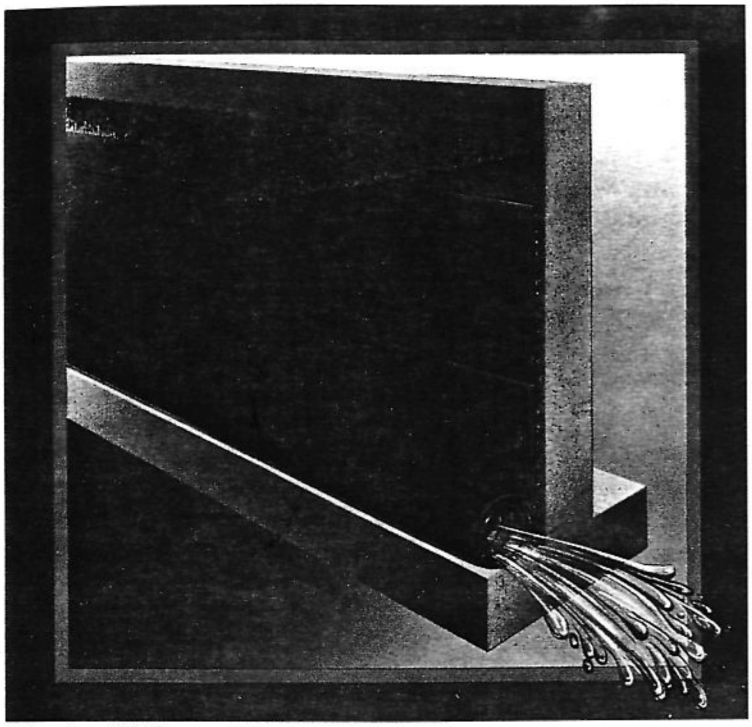
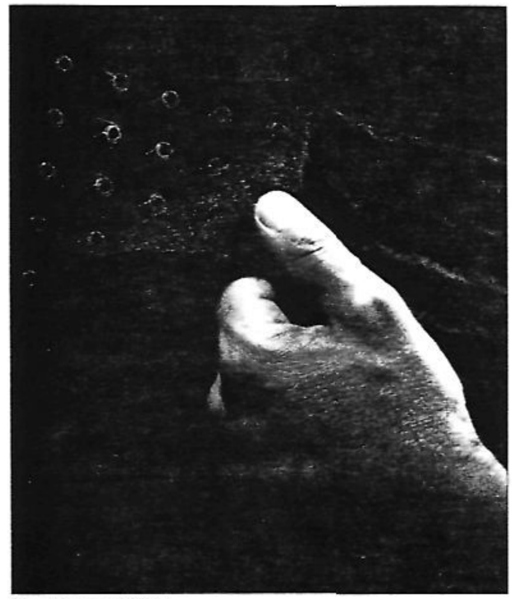
# *Hydraway® Drain*

## *Subsurface Geocomposite Drainage Systems*

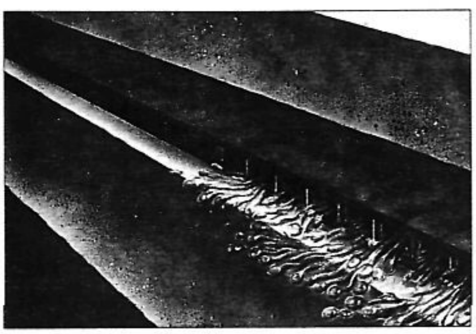
*ENVIRONMENTALLY FRIENDLY*



Structural Walls

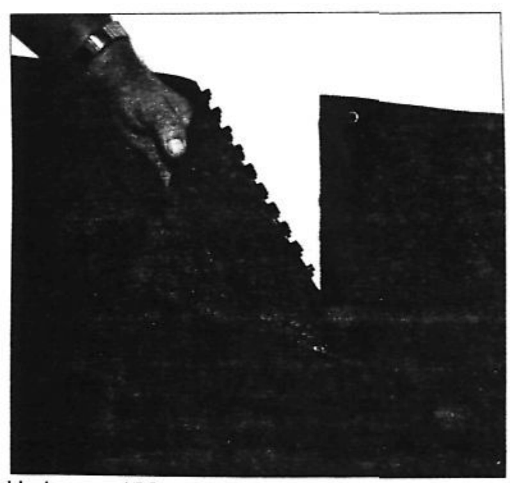


Hydraway 300



Horizontal Applications

Industrial Foundations



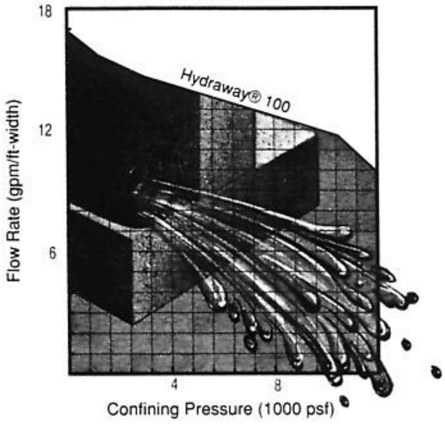
Hydraway 100

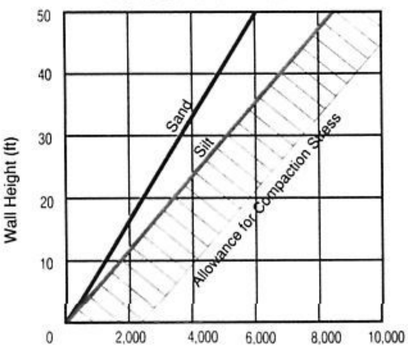
## Hydraway 100

**Basic Use:** Relieves Hydrostatic pressure against subsurface structures when membranes are not required.

**Applications:** Retaining walls, foundations, concrete holding tanks, bridge abutments, plaza decks and planters.

**Limitations:** This product should not be used where it will be subjected to temperatures in excess of 200° F.

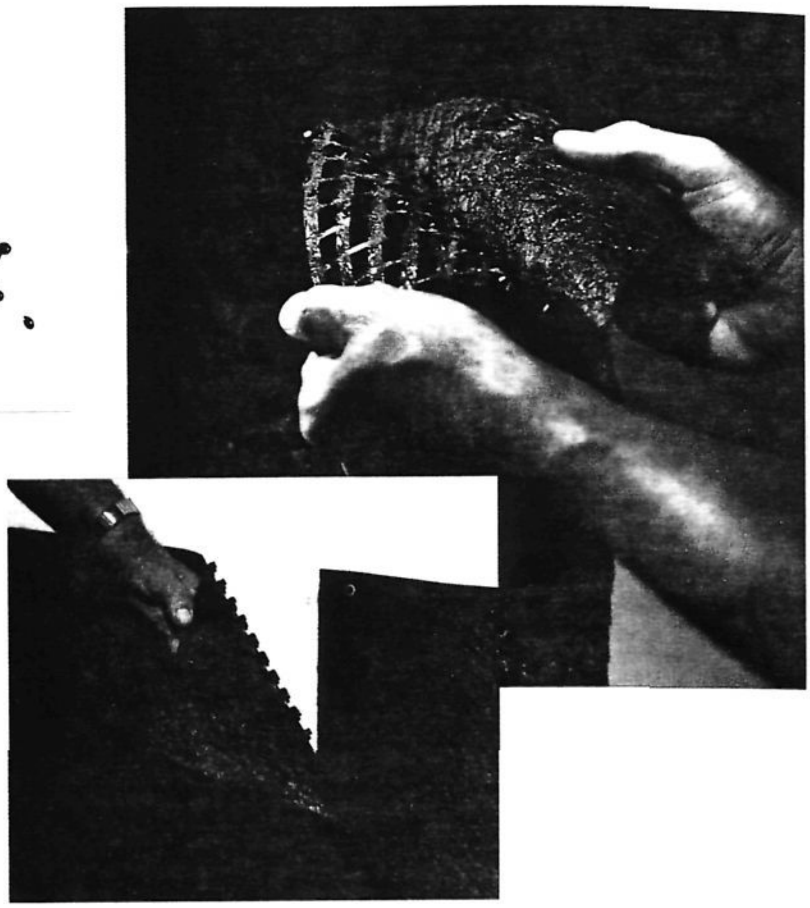


Maximum at rest lateral earth pressure versus wall height for vertical retaining walls under saturated backfill conditions

**Features and Benefits:**

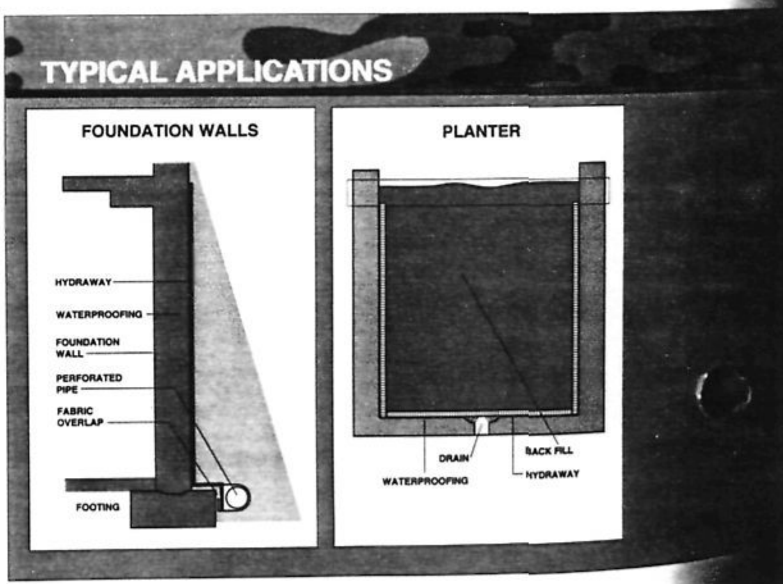
- **Polyethylene core** (vs. polystyrene) provides flexibility, light weight, and chemical resistance.
- **High compressive strength** means superior performance in deep foundations, even where soil loads are in excess of 12,000 psf.
- **High flow rate** means better drainage in all applications.
- **Fusion bonding** (vs. gluing) the core and fabric provides fungus resistance, and keeps the fabric firmly attached in high heat and humidity.
- **Individually wrapped rolls and flexibility** assure easy installation, even at cold temperatures.



## Physical Properties

| Product | Test Method | Typical Value |
|---|---|---|
| Compressive Strength | ASTM D-695/1621[2] | 16,000 psf |
| Flow Rate at 1500 psf | ASTM D-4716[1] | 16 gpm/ft-width |
| at 3600 psf | ASTM D-4716[1] | 15 gpm/ft-width |
| Thickness | ASTM D-1777 | .38 inch |
| **Fabric (4.5 oz.)** | | |
| Elongation | ASTM D-4632 | 50% |
| Grab Tensile | ASTM D-4632 | 120 lbs. |
| Flow rate | ASTM D-4491 | 180 GPM/SF |
| AOS (EOS) | ASTM D-4751 CW-02215 | 80-100 |
| **Roll Dimensions** | | |
| Width | 36" | |
| Length | 82' | |
| SF/Roll | 246 | |
| Weight/Roll | 52 lbs. | |

1. Gradient of 1.0
2. Modified — An existing ASTM Test was modified, since a recognized test method has not been established for this type of product.



## Hydraway 300

**Basic Use:** Relieves Hydrostatic pressure against subsurface structures. Provides a built-in protection board in one-piece construction.

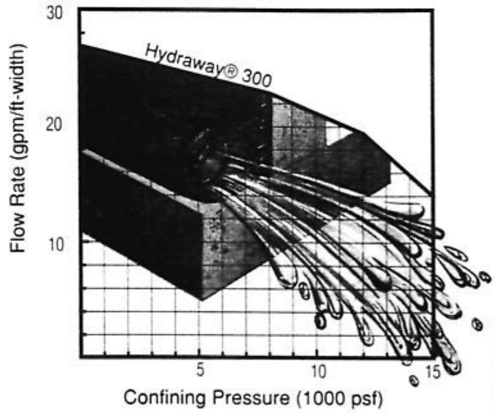
**Applications:** Retaining walls, foundations, concrete holding tanks, plaza decks and planters.

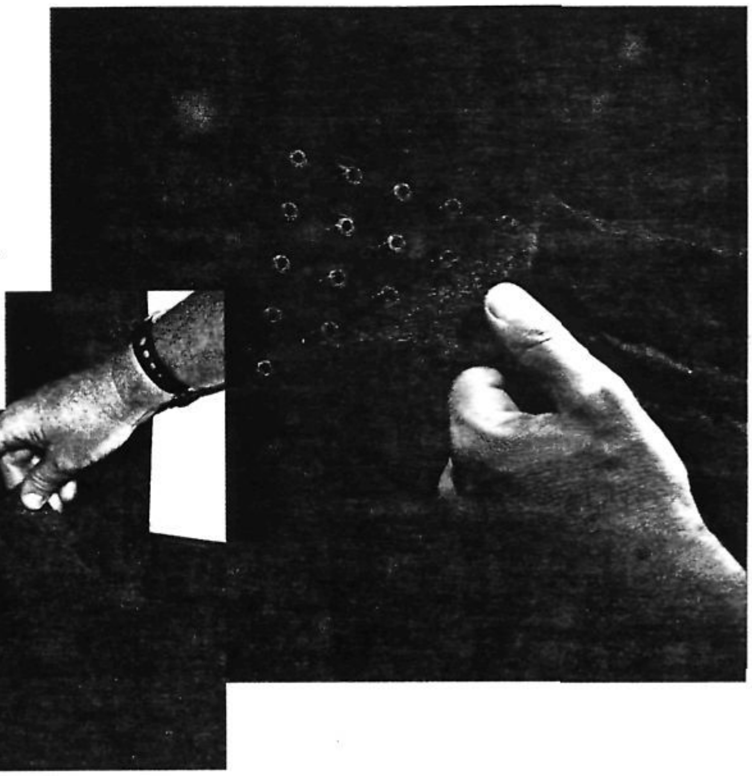
**Limitations:** This product should not be used where it will be subjected to temperatures in excess of 200° F.

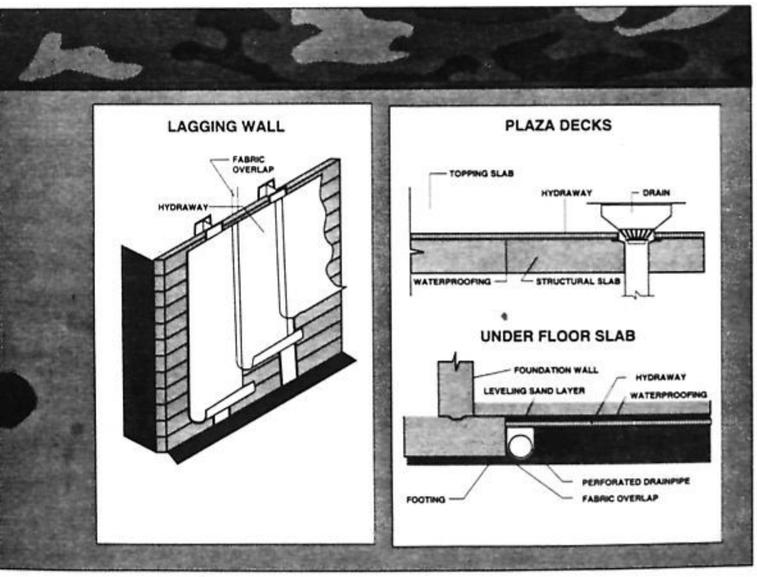
**Features and Benefits:**

- **Polyethylene core** (vs. polystyrene) provides flexibility, light weight, and chemical resistance.
- **High compressive strength** means superior performance in deep foundations, even where soil loads are in excess of 15,000 psf. Hydraway 300 can be used to soil depths in excess of 50 feet.
- **High flow rate** means better drainage in all applications.
- **Fusion bonding** (vs. gluing) the core and fabric provides fungus resistance, and keeps the fabric firmly attached in high heat and humidity.
- **Built-in protection board** and one-piece construction reduces overall costs by eliminating need for added protection board.
- **Individually wrapped rolls and flexibility** assure easy installation, even at cold temperatures.

**Flow vs. Load** [1]






## Physical Properties

| Product | Test Method | Typical Value |
|---|---|---|
| Compressive Strength | ASTM D-695/1621[2] | 19,000 psf |
| Flow Rate at 1500 psf | ASTM D-4716[1] | 27 gpm/ft-width |
| at 3600 psf | ASTM D-4716[1] | 22 gpm/ft-width |
| Thickness | ASTM D-1777 | .42 inch |
| **Fabric (5.5 oz.)** | | |
| Elongation | ASTM D-4632 | 50% |
| Grab Tensile | ASTM D-4632 | 160 lbs. |
| Flow Rate | ASTM D-4491 | 130 GPM/SF |
| AOS (EOS) | ASTM D-4751 CW-02215 | 100-120 |
| **Roll Dimensions** | | |
| Width | 38" | |
| Length | 82' | |
| SF/Roll | 260 | |
| Weight/Roll | 66 lbs. | |

1. Gradient of 1.0
2. Modified — An existing ASTM Test was modified, since a recognized test method has not been established for this type of product.

**Hydraway 2000**

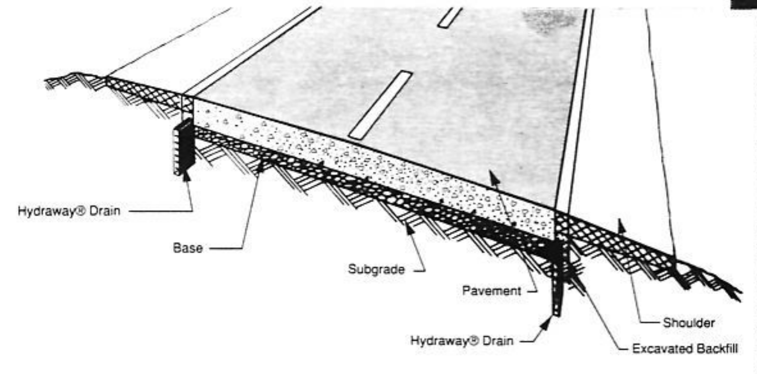
**Basic Use:** Relieves Hydrostatic pressure by acting as a shallow underdrain. Hydraway 2000 is a superior performing and cost effective replacement for the "french" drain (fabric, perforated pipe and aggregate).

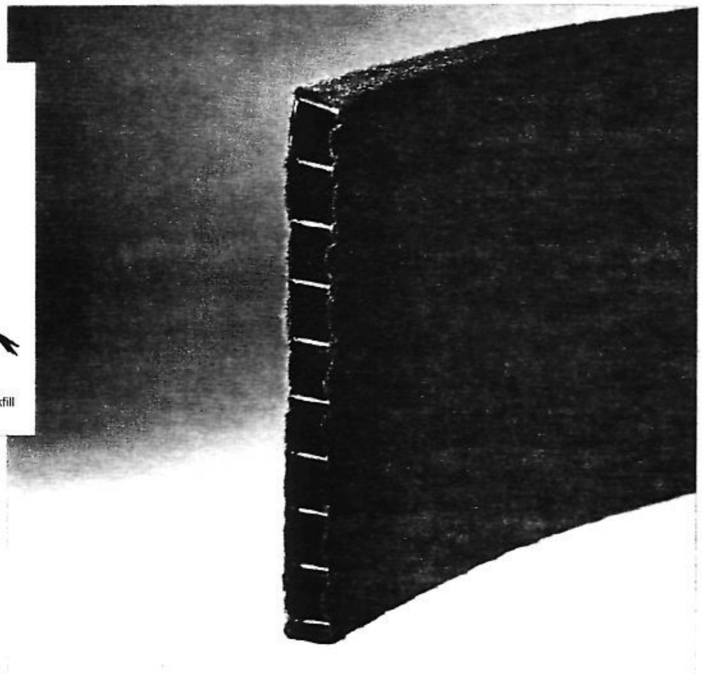
**Applications:** Highway and airport pavements, parking lots, golf courses, recreational fields and residential foundations.

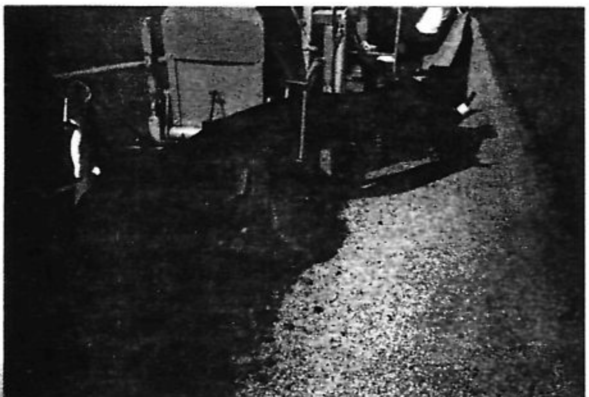
**Limitations:** This product should not be used where it will be subjected to temperatures in excess of 200° F.

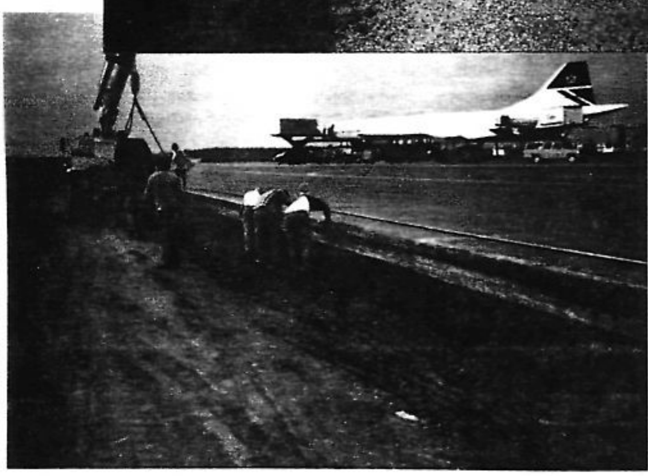
**Features and Benefits:**

- Polyethylene core (vs. polystyrene) provides flexibility, light weight and chemical resistance.
- Replaces the fabric, perforated pipe and aggregate backfill required in most traditional drain systems.
- Backfill uses excavated material.
- Machine installed using conventional trenching equipment.
- Requires less labor and equpment than traditional drain systems.
- Fusion bonding (vs. gluing) the core and fabric provides fungus resistance, and keeps the fabric firmly attached in high heat and humidity.
- Built-in protection board and one-piece construction reduces overall costs by eliminating need for added protection board.
- Individually wrapped rolls and flexibility, assure easy installation even at cold temperatures.







## Physical Properties

| Product | Test Method | Typical Value |
|---|---|---|
| Compressive Strength | ASTM D-695/1621[2] | 9,200 psf |
| Flow Rate at 1500 psf | ASTM D-4716[1] | 21 gpm/ft-width |
| Peel Strength[3] | ASTM D-1876 | 35 lbs/ft-width |
| **Fabric (5.5 oz.)** | | |
| Elongation | ASTM D-4632 | 50% |
| Grab Tensile | ASTM D-4632 | 160 lbs. |
| Flow Rate | ASTM D-4491 | 130 GPM/SF |
| AOS (EOS) | ASTM D-4751<br>CW-02215 | 100-120 |
| **Roll Dimensions** | | |
| Width | 6" to 36" | |
| Length | up to 550' | |

1. Gradient of 0.1
2. Modified — An existing ASTM Test was modified, since a recognized test method has not been established for this type of product.
3. Fabric to core.

**Monsanto**

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# PRODUCT COMPARISON DATA

| | CORE | | | FABRIC | | | COMPOSITE | | |
|---|---|---|---|---|---|---|---|---|---|
| | WT OZ/SF | THICK IN | COMP STR KPSF | AOS (EOS) SIEVE | GRAB LBS | WT OZ SY | FLOW 3600 1.0 GPM SF | FLOW 3600 .1 GPM SF | DESCRIPTION |
| **MONSANTO** | | | | | | | | | |
| **H-100** | **3.2** | **.38** | **16** | **80-100** | **120** | **4.5** | **15** | **5** | |
| **H-300** | **3.9** | **.42** | **19** | **100-120** | **160** | **5.5** | **22** | **7** | **WITH PROTECTION BOARD** |
| MIRADRAIN | | | | | | | | | |
| 2000 | 1.8 | .25 | 10.8 | 100 | 100 | 4.0 | 7 | 2 | |
| 6000 | 2.3 | .38 | 15 | 100 | 100 | 4.0 | 15 | 3 | |
| 6200 | 2.8 | .40 | 15 | 100 | 100 | 4.0 | 15 | 3 | 6K+SHEET |
| 9000 | 2.4 | .38 | 21 | 70-100 | 400x250 | 6.3 | 18 | 5 | WOVEN |
| J-DRAIN (NET) | | | | | | | | | |
| 100 | 4.2 | .25 | 30 | 70-100 | 120 | 4.5 | 8[1] | | NET |
| 300 | 3.3 | .22 | 30 | 70-100 | 120 | 4.5 | 7 | | NET |
| 1000 | 5.4 | .25 | 30 | 70-100 | 120 | 4.5 | 7 | | +SHEET |
| GREENSTREAK[2] | | | | | | | | | |
| SHEET DRAIN | 3.4 | .38 | 15 | 70 | 100 | 4.0 | 21 | | M-6000 |
| SHEET DR HS | 2.2 | .21 | 25 | 70 | 100 | 4.0 | 6 | | |
| DECK DRAIN | 3.7 | .38 | 20 | 30-50 | 300x200 | 6.5 | 21 | | WOVEN |
| ENKADRAIN | | | | | | | | | |
| 9010 | 1.2 | .40 | NP | 70-120 | 130 | 4.3 | NA | NA | MESH |
| 9120 | 2.4 | .80 | NP | 70-120 | 130 | 4.3 | NA | NA | MESH |
| AMER. WICK | | | | | | | | | |
| 500 | 2.9 | .38 | 15 | 80 | 115 | 4.0 | 16 | | M-6000 |
| 520 | 3.0 | .38 | 15 | 80 | 115 | 4.0 | 16 | | 500+SHEET |
| 650 | 2.9 | .38 | 21 | 100 | 410x285 | 6.6 | 16 | | WOVEN |
| GRACE | | | | | | | | | |
| HYDRODUCT | NP | .38 | 15 | 70 | 100x135 | 4.0 | 15 | | |
| *HYDRODUCT 2* | *NP* | .38 | 15 | 70 | 100x135 | 4.0 | 15 | | *HDUCT+SHEET* |
| HYDRODUCT HSF | NP | .38 | 18 | 70-100 | 400x250 | NP | 15 | | WOVEN |

1 - @ 6000 PSF     2 - MARV     NP - Not Published

# HYDRAWAY™ 100 INSTALLATION INSTRUCTIONS

## Pipe at Bottom of Footing - See Figure 1

1. The product is placed with the plastic core facing the wall and the fabric facing away from the wall. One edge of the roll has a 4 inch fabric flap. The rolls are always installed such that this flap edge is DOWN.

2. Lay the perforated pipe at the base of the footing as shown. Place a horizontal chalk line on the wall 30 inches above the top of the footing minus the width and height of the footing. This is to allow for sufficient product to cover the pipe. The top of the first row of product will be aligned with this chalk line.

3. Start the first row at the beginning of the wall. Peel 4 inches of fabric off of the beginning of the first roll of product to be installed and cut away the exposed plastic core. Tuck the 4 inches of fabric behind the product and tape it to the core.

4. Install the first roll with the fabric covered end placed at the beginning of the wall and the top edge of the product aligned with the chalk line created in Step 2. Place all rolls of product with the 4 inch fabric flap edge DOWN. Wrap the bottom of the product around the pipe as shown.

5. Attach the product to the wall using concrete nails and 2 inch washers driven through the product cylinders. The nails should be placed 2 inches to 6 inches from the top of the roll and spaced at about 4 foot intervals along the horizontal run of product.

6. Peel 4 inches of fabric from the end of this first roll and cut away the exposed core. This creates a 4 inch fabric flap to overlap the next roll of product placed in this row. Butt the next roll of product to the first roll and install it the same way as the first roll. The fabric flap from the end of the first roll should be taped over the seam between the first and second rolls.

7. Continue installing product in this manner to create the first row of drain. The product may be formed around inside or outside corners in the wall without loss of drainage efficiency.

8. When the end of the first row of drain is reached, cut the last roll 4 inches longer than the wall. Peel 4 inches of fabric off of the core and cut away the exposed core. For a retaining wall type installation, tuck the 4 inch fabric flap behind the product and tape it in place. For a foundation type installation, tape the 4 inch fabric flap down over the beginning of the first roll of product installed in this row.

9. To create the next row of drain, butt subsequent rolls of product, with the 4 inch flap DOWN, to the top edge of the first row so the 4 inch fabric flap covers the seam.

10. The top row of product should have it's top edge 6 inches to 12 inches below the soil surface. For the rolls of product in this row peel back sufficient fabric form the top edge to obtain this spacing. Cut off the exposed core and tuck the fabric behind it.

# HYDRAWAY™ 300 INSTALLATION INSTRUCTIONS

## Pipe at Bottom of Footing - See Figure 3

1. The product is placed with the plastic back facing the wall and the fabric facing away from the wall. One edge of the roll has a 4 inch fabric flap and the opposite edge has a 2 inch plastic flange. The rolls are always installed such that the fabric flap edge is **DOWN** and the plastic flange edge is **UP.**

2. Lay the perforated pipe at the base of the footing as shown. Place a horizontal chalk line on the wall 30 inches above the top of the footing minus the width and height of the footing. This is to allow for sufficient product to cover the pipe. The top of the first row of product will be aligned with this chalk line.

3. Start the first row at the beginning of the wall. Peel 4 inches of fabric off of the beginning of the first roll of product to be installed and cut away the exposed plastic core. Tuck the 4 inches of fabric behind the product and tape it to the core.

4. Install the first roll with the fabric covered end placed at the beginning of the wall and the top edge of the product aligned with the chalk line created in Step 2. Place all rolls of product with the 4 inch fabric flap edge **DOWN** and the plastic flange **UP.** Wrap the bottom of the product around the pipe as shown.

5. Attach the product to the wall using concrete nails and 2 inch washers **driven through the product cylinders.** The nails should be placed 2 inches to 6 inches from the top of the roll and spaced at about 4 foot intervals along the horizontal run of product. If installing over a membrane, use two sided tape or protection board adhesive to attach the drain to the membrane.

6. Peel 4 inches of fabric from the end of this first roll and cut away the exposed core. This creates a 4 inch fabric flap to overlap the next roll of product placed in this row. Butt the next roll of product to the first roll and install it the same way as the first roll. The fabric flap from the end of the first roll should be taped over the seam between the first and second rolls.

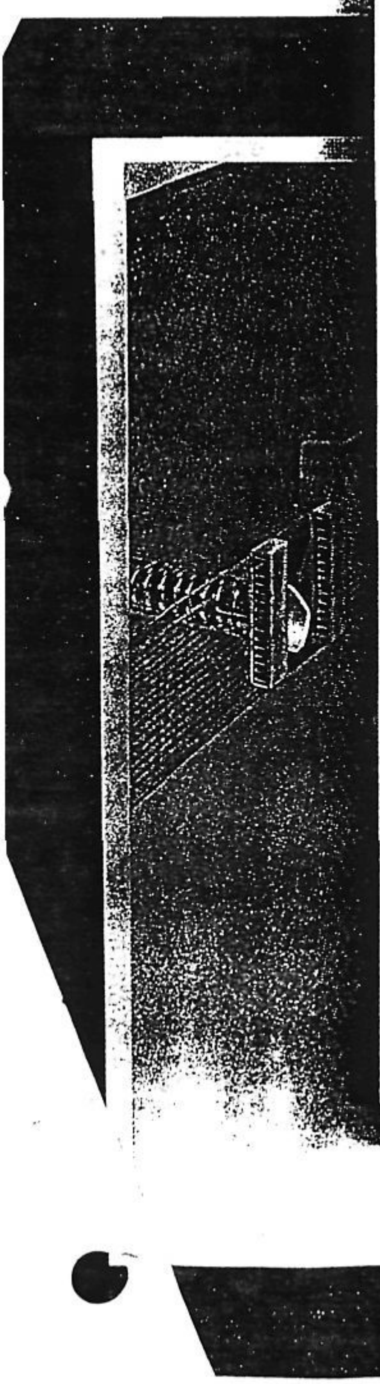
7. Continue installing product in this manner to create the first row of drain. The product may be formed around inside or outside corners in the wall without loss of drainage efficiency.

8. When the end of the first row of drain is reached, cut the last roll 4 inches longer than the wall. Peel 4 inches of fabric off of the core and cut away the exposed core. For a retaining wall type installation, tuck the 4 inch fabric flap behind the product and tape it in place. For a foundation type installation, tape the 4 inch fabric flap down over the beginning of the first roll of product installed in this row.

9. To create the next row of drain, butt subsequent rolls of product, with the 4 inch flap **DOWN,** to the top edge of the first row so the 4 inch fabric flap covers the seam and the top row ship laps the flange on the bottom row.

10. The top row of product should have it's top edge 6 inches to 12 inches below the soil surface. For the rolls of product in this row peel back sufficient fabric form the top edge to obtain this spacing. Cut off the exposed core and tuck the fabric behind it.

# Hydraway® DRAIN 2000



**Hydraway® Drain 2000** by Monsanto is a high-efficiency system for rapid water collection and removal from pavement systems.

Advanced design pays off in a system that offers these performance advantages over other products.

- 90% + open area on the pavement side for fast water removal;
- High compressive strength to withstand installation pressures and the ravages of freeze/thaw cycles;
- Strong, flexible design to conform to irregular trench walls, yet easy to install.

**Extraordinarily Tough Construction**
Hydraway Drain 2000 is made of heavy-duty, clog-resistance geotextile fabric, permanently bonded to a rugged polyethylene core lattice for strength and support. It resists the effects of hydrocarbons and offers outstanding low temperature flexibility.

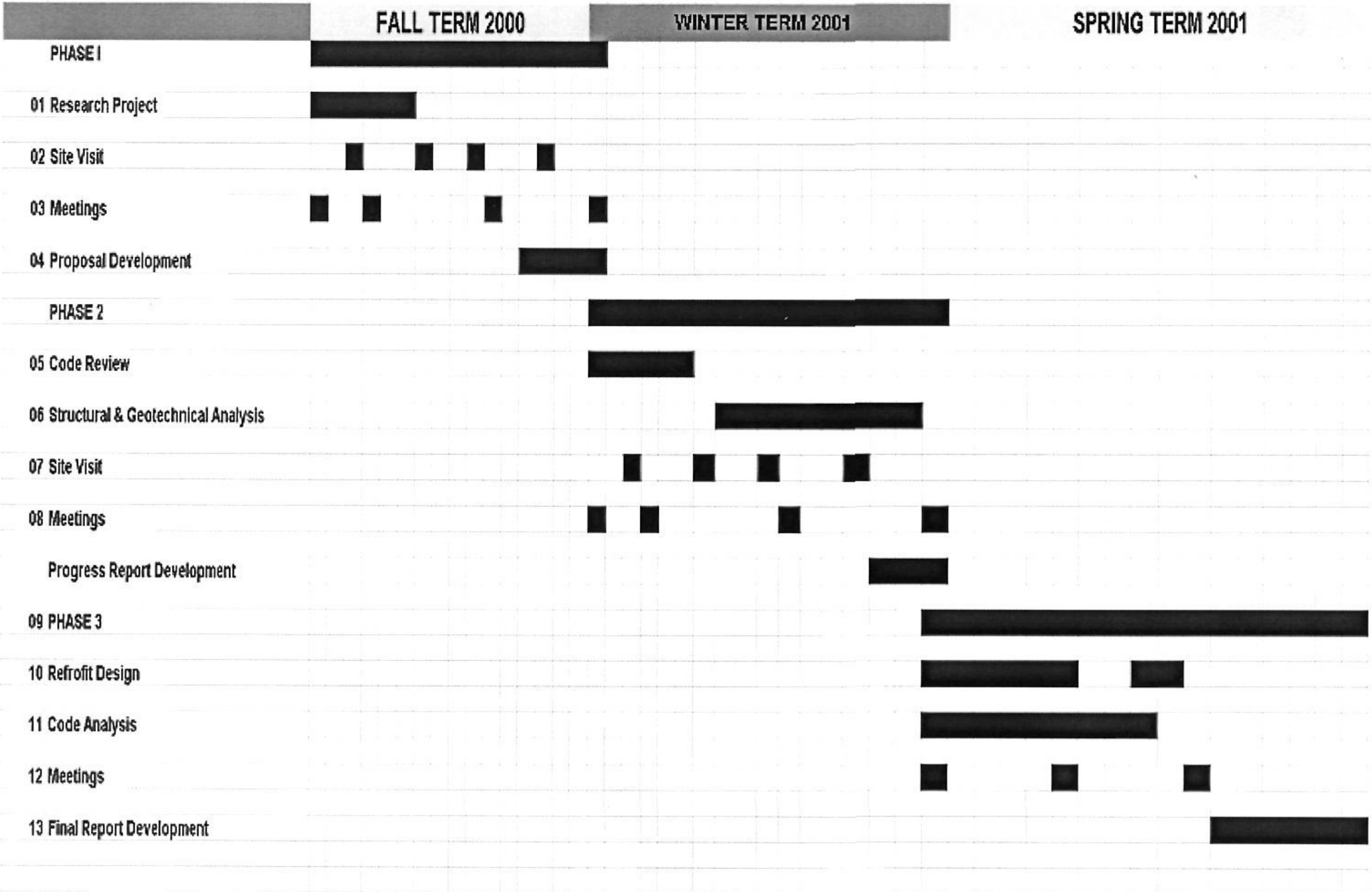
Specially-engineered design permits high flow rates for rapid dewatering of the pavement subbase, while effectively preventing passage of soil particles.

**Fast, Easy Installation**
Hydraway Drain 2000 is machine installed in a 4" wide trench, using conventional trenching equipment. Trench spoils are used as backfill, thereby eliminating the expense of aggregate and the need for aggregate trucks.

**Take Advantage of Monsanto's Experience**
Hydraway Drains have proven themselves in tens of thousands of miles of use, in over 30 states. These installations bear out the performance advantage of Hydraway:

- Fast, efficient installation with real savings in time and money;
- Faulting reduced by over 50% on I80;
- Six years of dependable service due to strong patented construction.

# RETROFIT SCHEDULE

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